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Environmental Assessment

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and Development Area, Nevada***

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Chapter 6

SUITABILITY OF THE YUCCA MOUNTAIN SITE FOR SITE CHARACTERIZATION AND FOR DEVELOPMENT AS A REPOSITORY

The Nuclear Waste Policy Act (the Act) of 1982 (NWP, 1983) requires the environmental assessment to include a detailed statement of the basis for nominating a site as suitable for characterization. This detailed statement is to be an evaluation of site suitability under the U.S. Department of Energy (DOE) siting guidelines; the evaluation will be the basis for the comparisons of sites reported in Chapter 7. Such an evaluation for the Yucca Mountain site is presented in sections 6.2, 6.3, and 6.4 of this chapter. A brief explanation of the siting guidelines--their format, structure, and implementation--is given in Section 6.1.

6.1 THE DOE SITING GUIDELINES

As directed by Section 112 of the Act, the DOE has developed general guidelines for siting geologic repositories. These guidelines have been published as 10 CFR Part 960 (1984). They are to be used in the remaining steps of the site-selection process for the first repository: the nomination of at least five sites as suitable for characterization, the recommendation of three sites for characterization, and the recommendation of one site for development as a repository.

6.1.1 FORMAT AND STRUCTURE OF THE GUIDELINES

The siting guidelines are divided into implementation guidelines, post-closure guidelines, and preclosure guidelines. The implementation guidelines are not directly used in the evaluation of sites; their purpose is to specify how the postclosure and preclosure guidelines are to be applied in site screening and selection. The postclosure guidelines govern the siting considerations that deal with the long-term behavior of a repository--that is, its behavior after waste emplacement and repository closure. These are the considerations most important for ensuring the long-term protection of the health and safety of the public. The preclosure guidelines govern the siting considerations that deal with the operation of the repository before it is closed. These are the considerations important in protecting the public and the repository workers from exposures to radiation during repository operations. They are also the most important considerations in protecting the quality of the environment and in mitigating socioeconomic impacts because most of the environmental and socioeconomic effects of a repository will occur during its construction and operation.

As explained in the supplementary information preceding the guidelines, both the postclosure and the preclosure guidelines are subdivided into system and technical guidelines. The postclosure system guideline defines general requirements for the performance of the repository system after closure.

These requirements are based generally on the objectives of protecting public health and safety; they are based specifically on the standards proposed by the U.S. Environmental Protection Agency and released as 40 CFR Part 191 (1985) and the criteria promulgated by the Nuclear Regulatory Commission in 10 CFR Part 60 (1983). The postclosure technical guidelines specify requirements for one or more elements of the repository system--the physical properties and physical phenomena at the site.

The three preclosure system guidelines state broad requirements for three different systems. These systems include, in addition to some characteristics of the site and some engineered components, the people and the environment near the site. The elements of these systems are defined in Section III.B.4 of the supplementary information preceding the guidelines. Each of the preclosure technical guidelines specifies requirements on one or more of these elements.

Both the postclosure and the preclosure technical guidelines specify conditions that would qualify and disqualify sites, and they specify conditions that would be considered favorable or potentially adverse.

A qualifying condition is contained in each technical guideline. Taken together, these qualifying conditions are the minimum conditions for site qualification. A site will be qualified only if it meets all of the qualification conditions. A site will be disqualified if site characterization shows that it fails to meet any one of the qualifying conditions. Failure to meet a qualifying condition can usually be determined only after site characterization and the concurrent investigations of environmental and socioeconomic conditions: qualifying conditions are generally stated in terms of specifications that require analyses of the repository system, and data for such analyses will be available only at the completion of site characterization and investigation. Before site characterization, however, evaluations that compare sites will reveal the relative potential of those sites to meet the qualifying conditions.

Disqualifying conditions are contained in 12 technical guidelines. Each describes a condition that is considered so adverse as to constitute sufficient evidence to conclude, without further consideration, that a site is disqualified. Many of the 17 disqualifying conditions pertain to conditions whose presence or absence may be verifiable at a site without extensive data gathering or complex analysis.

The favorable and potentially adverse conditions can be used to predict the suitability of a site before detailed studies have been performed. They provide preliminary indications of system performance. Although favorable conditions need not exist at a given site for that site to meet the qualifying condition, the existence of such conditions leads to an expectation that subsequent evaluations will yield enhanced confidence in a site's suitability. Similarly, the purpose of determining whether any potentially adverse conditions exist at a site is to provide an early indication of conditions that must be examined carefully before judging the acceptability of that site. Such examinations must evaluate the effects of other, possibly compensatory, conditions present at a site. Thus, a site that has most of the favorable conditions may be presumed likely to meet the system guidelines,

while a site with many potentially adverse conditions can be considered to have a much greater degree of uncertainty in meeting the system guidelines.

6.1.2 USE OF THE SITING GUIDELINES IN EVALUATING SITE SUITABILITY

The evaluations of site suitability provide the basis for making the findings that Appendix III of the guidelines requires for disqualifying and qualifying conditions. Using the term apply to mean to evaluate a condition and make a finding of compliance, this appendix specifies how the guidelines are to be applied at the principal decision points of the siting process: (1) site identification as potentially acceptable, (2) nomination as suitable for characterization or recommendation for characterization, and (3) recommendation for development as a repository. In particular, this appendix specifies the types of findings that are to result from the applications of the disqualifying conditions and the qualifying conditions. Two levels of findings, one showing an increased level of confidence over the other, are specified for both the disqualifying and the qualifying conditions.

For the disqualifying conditions, a level 1 finding means that the evidence does not (or, conversely, does) support a finding that the site is disqualified. A level 2 finding, which is a higher-level finding requiring greater confidence and more extensive data to support it, means that the evidence supports a finding that the site is not disqualified on the basis of existing evidence and is not likely to be disqualified (or that the site is disqualified or is likely to be disqualified).

For the qualifying conditions, a level 3 finding is stated to mean that the evidence does not (or, conversely, does) support a finding that the site is not likely to meet the qualifying condition, while a level 4 finding, which is the higher-level finding, means that the evidence supports a finding that the site meets the qualifying condition and is likely to continue to meet the qualifying condition (or that the site cannot meet the qualifying condition and is unlikely to be able to meet it).

For a site to be nominated, at least a level 1 finding must be made for each disqualifying condition, and at least a level 3 finding must be made for each qualifying condition. For a site to be recommended for development as a repository, a level 2 finding must be made and supported for each disqualifying condition, and a level 4 finding must be made and supported for each qualifying condition.

In conducting the suitability evaluations for the site, the higher-level finding was made wherever the evidence supported it. Most often, however, the available data were inadequate for supporting the higher-level findings, which must wait for the results of site characterization and investigations as well as for the final design of the repository.

An identification of the favorable conditions and potentially adverse conditions present at the site is necessary for evaluating the ability of the site to meet the individual qualifying conditions; before site characterization, that ability is determined largely by examining the balance between those conditions along with information on the repository system. The

identification of the favorable and potentially adverse conditions as present or not present at the site is based on data currently existing for the site or conservative assumptions when the existing data are inadequate for the identification. (Conservative assumptions are assumptions that minimize the possibility that later findings will prove the assumptions to be wrong.) In order for a favorable condition to be claimed as present, it is necessary for the existing data to clearly support that conclusion. Otherwise, the favorable condition is stated to be not present. Similarly, a potentially adverse condition is stated to be present unless the existing data and the conservative assumptions clearly support a conclusion that the condition is not present.

The process of making suitability evaluations and arriving at findings for the disqualifying and qualifying conditions is fully discussed and presented in the guideline-by-guideline evaluations in sections 6.2 and 6.3. The evidence required to support these evaluations includes the types of information specified in Appendix IV of the guidelines.

6.1.3 DIVISION OF THE GUIDELINES INTO CATEGORIES

The Nuclear Waste Policy Act of 1982 (the Act) (NWPA, 1983) requires two separate evaluations of the suitability of a site:

1. An evaluation as to whether a site is suitable for site characterization under the siting guidelines.
2. An evaluation as to whether a site is suitable for development as a repository under each guideline that does not require site characterization as a prerequisite for its application.

For making these two evaluations, the guidelines are divided into two categories according to whether they do or do not require site characterization as a prerequisite for their application. The basis for this division of the guidelines is the definition of site characterization in the Act. The Act defines site characterization essentially as activities undertaken to establish the geologic conditions at a candidate site, including borings, surface excavations, the sinking of exploratory shafts, and in-place testing at repository depth.

Therefore, in accordance with this definition, the guidelines requiring site characterization as a prerequisite to their application are those that contribute to establishing the geologic conditions at a site. The guidelines in this category are concerned predominantly with subsurface conditions, and most of them are postclosure guidelines. Section 6.3 presents the evaluations of the site against the guidelines in this category. The information required to establish compliance with these guidelines will be obtained during site characterization.

The guidelines not requiring site characterization as a prerequisite to application are those that do not contribute to establishing the geologic conditions at a site. The guidelines in this category are predominantly

concerned with surface conditions, and most of them are preclosure guidelines. The information required to establish compliance with these guidelines may be obtained before or during site characterization. Section 6.2 presents the evaluations of the site against the guidelines in this category.

Table 6-1 lists the guidelines in each category and shows the levels of findings that were made in accordance with Appendix III of the guidelines.

6.1.4 FORMATS FOR THE PRESENTATION OF SITE EVALUATIONS

In sections 6.2 and 6.3, the presentation of each technical guideline begins with an introduction that states the qualifying condition for that guideline and briefly explains the objectives and the structure of the guideline. The introduction is followed by a section that reviews or cites the data available for the evaluations against the guideline, explains the general assumptions that must be made, and discusses the uncertainties in the data. Each favorable, potentially adverse, and disqualifying condition is then discussed in turn; each discussion evaluates the presence or absence of the condition and states a conclusion based on that evaluation. Finally, the ability of the site to meet the qualifying condition is examined, and a conclusion is presented. For the disqualifying and qualifying conditions, the conclusion is presented as a finding at one of the levels specified by Appendix III of the guidelines (Section 6.1.2).

The format for presenting the system guidelines is similar, but it omits the discussion of favorable, potentially adverse, and disqualifying conditions because none of these conditions appear in the system guidelines.

The conclusions drawn in these presentations are different in Section 6.2 and in Section 6.3. Because the guidelines in Section 6.2 do not require site characterization, the conclusion refers to the suitability of the site for development as a repository. Such a conclusion cannot be drawn for guidelines that require site characterization as a prerequisite for their application; only after site characterization can the question of suitability for repository development be addressed. Rather, the appropriate conclusion for these guidelines is whether the site is suitable for further study. The conclusions presented in Section 6.3, therefore, refer only to the suitability of the site for characterization.

Table 6-1. Level of finding for qualifying and disqualifying conditions

Guideline	Level of finding for disqualifying condition ^a	Level of finding for qualifying condition ^b
POSTCLOSURE GUIDELINES		
960.4-1 Postclosure System	NA ^c	3
960.4-2-1 Geohydrology	1	3
960.4-2-2 Geochemistry	NA	3
960.4-2-3 Rock characteristics	NA	3
960.4-2-4 Climatic changes	NA	3
960.4-2-5 Erosion	1	3
960.4-2-6 Dissolution	2	4
960.4-2-7 Tectonics	1	3
960.4-2-8 Human interference		
960.4-2-8-1 Natural resources		
Condition 1	1	3
Condition 2	1	3
960.4-2-8-2 Site ownership and control	NA	3
PRECLOSURE GUIDELINES		
960.5-1 Preclosure System		
Radiological safety	NA	3
Environment, socioeconomics, and transportation	NA	3
Ease and cost of siting, construction operation, and closure	NA	3
960.5-2-1 Population density and distribution		3
Condition 1	2	
Condition 2	2	
Condition 3	1	
960.5-2-2 Site ownership and control	NA	3
960.5-2-3 Meteorology	NA	3
960.5-2-4 Offsite installations and operations	1	3
960.5-2-5 Environmental quality		3
Condition 1	1	
Condition 2	1	
Condition 3	1	
960.5-2-6 Socioeconomic impacts	1	3
960.5-2-7 Transportation	NA	3
960.5-2-8 Surface characteristics	NA	3
960.5-2-9 Rock characteristics	1	3
960.5-2-10 Hydrology	1	3
960.5-2-11 Tectonics	1	3

^aUnless otherwise noted, the guideline has only one disqualifying condition.

^bEach guideline has only one qualifying condition.

^cNA = Not applicable; guideline has no disqualifying condition.

6.2 SUITABILITY OF THE YUCCA MOUNTAIN SITE FOR DEVELOPMENT AS A REPOSITORY: EVALUATION AGAINST THE GUIDELINES THAT DO NOT REQUIRE SITE CHARACTERIZATION

This section presents preliminary evaluations of the Yucca Mountain site against the eight technical guidelines and the two system guidelines that do not require data from site characterization as a prerequisite to their application. The technical guidelines are discussed first.

6.2.1 TECHNICAL GUIDELINES

Seven preclosure technical guidelines and one postclosure guideline are evaluated in this section. The qualifying condition for each technical guideline is presented at the beginning of the discussion of the guideline; it provides a framework for discussion of the associated favorable and potentially adverse conditions. An introduction describes the objective of the guideline and then refers the reader to a summary table that states the entire guideline, the conclusions for each favorable and potentially adverse condition, and the preliminary evaluation of the qualifying condition. For the disqualifying conditions associated with these technical guidelines, a separate summary table and text summaries are presented in Section 2.3. In this chapter, after a description of the sources of relevant data, a series of detailed evaluations provide the basis for the determination of whether each favorable or potentially adverse condition is present or not present at the Yucca Mountain site. Finally, the evaluation and conclusion for the qualifying condition summarize the favorable and potentially adverse conditions, as well as introduce any other information that supports the finding for the qualifying condition.

6.2.1.1. Postclosure site ownership and control (10 CFR 960.4-2-8-2)

6.2.1.1.1 Introduction

The qualifying condition for this guideline is as follows:

The site shall be located on land for which the DOE can obtain, in accordance with the requirements of 10 CFR Part 60, ownership, surface and subsurface rights, and control of access that are required in order that potential surface and subsurface activities at the site will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.

This site ownership and control technical guideline is a subpart of the postclosure human interference technical guideline. The objective of this guideline is to ensure that the U.S. Department of Energy obtains land ownership, in accordance with the requirements of 10 CFR 60.121 (1983), in order to establish passive controls following closure of the repository and thus decrease the likelihood of future human activities that would compromise the integrity of the repository. Passive controls include permanent markers on

the surface above the underground portion of the repository and records available to future generations.

The postclosure site ownership and control guideline consists of one favorable condition, one potentially adverse condition, and one qualifying condition. The evaluations against these conditions are summarized in Table 6-2.

6.2.1.1.2 Data relevant to the evaluation

The Yucca Mountain site is wholly on federally owned land. However, as explained below, three different agencies currently have jurisdiction and control over portions of the site. The eastern portion of the site is within the boundaries of the Nevada Test Site (NTS) under the control of the U.S. Department of Energy (DOE). The northwestern portion is on the Nellis Air Force Range (NAFR) under the control of the Department of the Air Force (DAF). The southwestern portion is on land in the public domain under the jurisdiction of the Bureau of Land Management (BLM) of the Department of the Interior (DOI). Figure 3-1 shows the location of these segments. If land is acquired and a repository is built at Yucca Mountain, a system of markers as described by Kaplan (1982) could be installed to prevent potential human interference with the repository.

Nevada Test Site segment

Pursuant to Public Land Order 2568, December 19, 1961, (DOI, 1961) this land has been withdrawn from all forms of appropriation under the public land laws, including the mining laws, and is under the jurisdiction and control of the DOE. The DOI has jurisdiction and control over "the mineral resources and mineral and vegetable materials" of the land. The DOE has control over all other surface and subsurface rights, including water rights from points of extraction on the land. The private acquisition of any surface or subsurface rights is presently precluded by virtue of the current public land order.

Nellis Air Force Range segment

Withdrawal legislation for the entire NAFR is currently before Congress. Until such time as this legislation is enacted, the BLM serves as the official protector of the land and custodian of all surface and subsurface rights. Private acquisition of any rights on or in the land is presently precluded pursuant to Section 204 of the Federal Land Policy and Management Act of 1976.

Bureau of Land Management segment

All land in this segment is in the public domain under the jurisdiction and management of the BLM and has not been segregated from the operation of the public land laws.

Table 6-2. Summary of analyses for Section 6.2.1.1; postclosure site ownership and control
(10 CFR 960.4-2-8-2)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITION	
Present ownership and control of land and all surface and subsurface rights by the DOE.	The evidence indicates that this favorable condition is not present at Yucca Mountain: the DOE presently does not exercise jurisdiction and control over all the land that would make up the site.
POTENTIALLY ADVERSE CONDITION	
Projected land-ownership conflicts that cannot be successfully resolved through voluntary purchase-sell agreements, nondisputed agency-to-agency transfers of title, or Federal condemnation proceedings.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: withdrawal action would have been taken prior to constructing the proposed repository. Additional withdrawals or transfers would not be necessary for the postclosure period.
QUALIFYING CONDITION	
The site shall be located on land for which the DOE can obtain, in accordance with the requirements of 10 CFR Part 60, ownership, surface and subsurface rights, and control of access that are required in order that potential surface and subsurface activities at the site will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.	Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): all land in question is now owned by the Federal government; the portions of the site not presently under DOE jurisdiction are under the jurisdiction and control of the U.S. Department of the Air Force and the Bureau of Land Management. The DOE plans to obtain control through interagency transfer. Future site activities are not likely to cause radionuclide releases in excess of allowable limits.

All the above lands are currently free and clear of encumbrances arising under lease, right of entry, deed, patent, mortgage, appropriation, prescription, or otherwise (Lutsey and Nichols, 1972). The land use and withdrawal actions necessary for site characterization and for developing a geologic repository are described in a plan developed by the Nevada Nuclear Waste Storage Investigations Project (Richards and Vieth, 1983). The plan outlines the actions necessary for land acquisition to meet the requirements of 10 CFR 60.121 (1983).

Assumptions and data uncertainties

Uncertainties about the site ownership and control are related to inter-agency negotiations involving the DAF and BLM over land withdrawal and restrictions. Although the DOE has control over water rights from points of extraction on the NTS, it is possible that superior rights to the water in the same underground source may exist with respect to some point of extraction outside the NTS boundaries.

6.2.1.1.3 Favorable condition

Present ownership and control of land and all surface and subsurface rights by the DOE.

Evaluation

Control of the land where the proposed site is located currently resides with the U.S. Department of Energy (DOE) (the Nevada Test Site portion), the U.S. Department of the Air Force (DAF) (the Nellis Air Force Range portion), and the Bureau of Land Management (BLM). Permanent withdrawal and reservation of jurisdiction and control over surface and subsurface rights requires Congressional approval. This transfer could be implemented as described in the above-mentioned Nevada Nuclear Waste Storage Investigations Project plan for land use and withdrawal.

Conclusion

Presently, the DOE exercises jurisdiction and control over only a portion of the Yucca Mountain site; the remaining portions are under the jurisdiction and control of the DAF and the BLM. Therefore, the evidence indicates that this favorable condition is not present at Yucca Mountain. However, because the remaining portions of the proposed site are owned by the Federal Government, it is expected that, at a later date, the DOE can acquire jurisdiction and control over the land, including all surface and subsurface rights.

6.2.1.1.4 Potentially adverse condition

Projected land-ownership conflicts that cannot be successfully resolved through voluntary purchase-sell agreements, nondisputed agency-to-agency transfers of title, or Federal condemnation proceedings.

Evaluation

While one portion of the Yucca Mountain site lies within the Nevada Test Site (NTS) and already is under the jurisdiction and control of the U.S. Department of Energy (DOE), the site also includes tracts of land under the jurisdiction of the U.S. Department of the Air Force (DAF) and the Bureau of Land Management (BLM). The air space above the DAF portion is a small, remote section of the Nellis Air Force Range (NAFR) which is used only as a flight corridor for military aircraft, and the BLM portion is a tract immediately adjacent to the already restricted lands of the NAFR and the NTS on which no other activities are presently occurring and no privately held rights or encumbrances have been identified as existing. Withdrawal of the BLM portion from the public domain and transfer of control over the DAF portion would have been accomplished prior to construction of the proposed repository in order for the DOE to obtain jurisdiction and control over the entire site (Richards and Vieth, 1983).

Conclusion

Withdrawal action necessary for the DOE to obtain jurisdiction and control over a portion of the site is planned to be accomplished prior to the construction of the proposed repository. No additional land withdrawal action will be necessary for the postclosure period. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain. However, in view of the absence of conflicts over land use for the lands to be withdrawn before repository construction would begin, no impediments to the obtaining of control by the DOE are projected.

6.2.1.1.5 Evaluation and conclusion for the qualifying condition on the postclosure site ownership and control guideline

Evaluation

Control of the Yucca Mountain site presently resides with the U.S. Department of Energy (DOE), the Bureau of Land Management (BLM), and the U.S. Department of the Air Force (DAF). The Nevada Nuclear Waste Storage Investigations Project has prepared a plan for land use and withdrawal actions for the DOE to acquire jurisdiction over the necessary land from the BLM and the DAF. No existing privately held rights or encumbrances, which would necessitate government purchase or condemnation action, have been identified for any portion of the site. The implementation of Congressional action necessary for permanent transfer to the DOE has been deferred pending selection of the site for a repository. Once the land is under DOE jurisdiction, the DOE would be able to control access to it. Permanent markers would be used to mark the controlled area, which extends horizontally no more than 5 kilometers (3.1 miles) in any direction from the boundary of the underground facility and subsurface area committed to the repository. A permanent marker and information system could use four types of messages: (1) an obvious notification to possible intruders that something is located there; (2) a warning that what is located at the site is dangerous (e.g., the symbol for radioactive material); (3) basic information such as what actions must be avoided, what is located at the site, who placed it there, and where

to find additional information; and (4) a full record of information, such as plans, drawings, and environmental impact statements (Kaplan, 1982). The markers and records would be used to discourage future generations from deliberately or inadvertently disturbing the Yucca Mountain site after closure.

Conclusion

The plan by which the DOE would acquire jurisdiction and control over all surface and subsurface rights for the Yucca Mountain site will be implemented if the site is selected for a repository. No impediments to eventual complete ownership and control by the DOE have been identified. Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition for postclosure site ownership and control (level 3).

6.2.1.2 Population density and distribution (10 CFR 960.5-2-1)

6.2.1.2.1 Introduction

The qualifying condition for this guideline is as follows:

The site shall be located such that, during repository operation and closure, (1) the expected average radiation dose to members of the public within any highly populated area will not be likely to exceed a small fraction of the limits allowable under the requirements specified in Section 960.5-1(a)(1), and (2) the expected radiation dose to any member of the public in an unrestricted area will not be likely to exceed the limit allowable under the requirements specified in Section 960.5-1(a)(1).

The population density and distribution technical guideline is one of four preclosure guidelines concerned with preclosure radiological safety. The objective of the guideline is to ensure the selection of a repository site that will minimize the risk to the public and permit compliance with the U.S. Environmental Protection Agency and the Nuclear Regulatory Commission regulations.

The guideline consists of two favorable conditions, two potentially adverse conditions, three disqualifying conditions, and one qualifying condition. The Yucca Mountain site is evaluated with respect to all these conditions in the following sections; and Table 6-3 summarizes the pertinent findings for all conditions except the disqualifying conditions.

6.2.1.2.2 Data relevant to the evaluation

This section presents data on population and population density, approximate distances from the proposed location of the surface facilities (measured in a straight line, not along existing road networks, on maps in the Nevada Map Atlas, State of Nevada, Department of Transportation, ca. 1984) and information on potential radiation doses to members of the public.

Table 6-3. Summary of analyses for Section 6.2.1.2; population density and distribution
(10 CFR 960.5-2-1)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITIONS	
(1) A low population density in the general region of the site.	The evidence indicates that this favorable condition is present at Yucca Mountain: the site is located in a county with a population density of 0.5 person per square mile; the population density in the nearby areas is well below the continental U.S. average.
(2) Remoteness of the site from highly populated areas.	The evidence indicates that this favorable condition is present at Yucca Mountain: the proposed location of the surface facilities at Yucca Mountain is remote from the nearest highly populated area, which is about 137 kilometers (85 miles) away.
POTENTIALLY ADVERSE CONDITIONS	
(1) High residential, seasonal, or daytime population density within the projected site boundaries.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: there is no seasonal, daytime, or residential population within the projected site boundaries.
(2) Proximity of the site to highly populated areas, or to areas having at least 1,000 individuals in an area 1 mile by 1 mile as defined by the most recent decennial count of the U.S. census.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: the nearest area 1 mile by 1 mile having a population of at least 1,000 is about 137 kilometers (85 miles) from the proposed location of the surface facilities.

Table 6-3. Summary of analyses for Section 6.2.1.2; population density and distribution
(10 CFR 960.5-2-1) (continued)

Condition	Department of Energy (DOE) finding
QUALIFYING CONDITION	
<p>The site shall be located such that, during repository operation and closure, (1) the expected average radiation dose to members of the public within any highly populated area will not be likely to exceed a small fraction of the limits allowable under the requirements specified in Section 960.5-1(a)(1), and (2) the expected radiation dose to any member of the public in an unrestricted area will not be likely to exceed the limit allowable under the requirements specified in Section 960.5-1(a)(1).</p>	<p>Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): the site is in an area of extremely low population density; radiation doses are not expected to exceed a small fraction of the limits specified for members of the public in unrestricted areas.</p>

In 10 CFR 960.2 (1984), a highly populated area is defined as, "Any incorporated place (recognized by the decennial reports of the U.S. Bureau of the Census) of 2,500 or more persons, or any census designated place (as defined and delineated by the Bureau) of 2,500 or more persons, unless it can be demonstrated that any such place has a lower population density than the mean value for the continental United States. Counties or county equivalents, whether incorporated or not, are specifically excluded from the definition of "place" as used herein." For purposes of this analysis, the mean population density of the continental United States is 76 persons per square mile, as shown in the 1985 Statistical Abstract of the United States (DOC, 1984) for the conterminous United States in 1980.

Nye County, where the Yucca Mountain site is located, had a 1980 population density of 0.5 person per square mile (Section 3.6.2.2). Gabbs, the only incorporated city in Nye County in 1980, had a population of 811 (DOC, 1981), and is located about 248 kilometers (154 miles) northwest of the proposed location of the surface facilities. Tonopah, the only census designated place in the county in 1980, had a population of 1,952. It is located about 153 kilometers (95 miles) to the northwest. There are no residential inhabitants within a 10-kilometer (6.2-mile) radius of the Yucca Mountain site; and all land within this radius is currently federally controlled and not open to settlement. Population values for Nye County communities nearest the Yucca Mountain site were not reported at the community level by the 1980 census. Estimates of their population values as reported in Smith and Coogan (1984), are discussed below. Their approximate distances (in a straight line, not along existing road networks) from the proposed location of the surface facilities are also given.

The nearest population center is located in the unincorporated Town of Amargosa Valley, residents of which are spread out in numerous small settlements within its estimated 1,036 square kilometers (400 square miles) (Section 3.6.4.1.1). Major population concentrations are located in the community formerly called Lathrop Wells, and now also called Amargosa Valley, approximately 23 kilometers (14 miles) to the south; the Amargosa Farm area, approximately 37 kilometers (23 miles) to the south; and the American Borate housing complex roughly 45 kilometers (28 miles) to the south. Population of these areas in 1984 was estimated to be 45, 1,500, and 280, respectively (Smith and Coogan, 1984). An estimate of the total population of the unincorporated town is not available (Section 3.6.2.2).

Beatty, located about 31 kilometers (19 miles) to the northwest had a 1984 estimated population of 800 (Smith and Coogan, 1984). Pahrump's 1984 population was estimated to be 5,500 (Smith and Coogan, 1984). It is located slightly more than 80 kilometers (50 miles) to the southeast.

Two rural counties adjacent to Nye County are Esmeralda and Lincoln. Their boundaries are located approximately 68 kilometers (42 miles) and 48 kilometers (30 miles) west and east, respectively, from the proposed location of the surface facilities. The 1980 population density of Esmeralda County was 0.2 person per square mile, and that of Lincoln was 0.4 person per square mile (DOC, 1981). There were no incorporated cities or census designated places in Esmeralda County in 1980. The incorporated city of Caliente in Lincoln County had a 1980 population of 982. Lincoln County had no census designated places in 1980 (DOC, 1981).

Clark County, adjacent to the southeast part of Nye County (with a boundary about 48 kilometers (30 miles) east of the proposed location of the surface facilities), had a 1980 population density of 58.8 persons per square mile (Section 3.6.2.3). The nearest urban area is the Las Vegas Valley in Clark County. It includes the incorporated cities of Henderson, Las Vegas, and North Las Vegas, and the unincorporated towns and communities of East Las Vegas, Enterprise, Grand View, Lone Mountain, Paradise, Spring Valley, Sunrise Manor, and Winchester. The 1980 population density of the Las Vegas Valley was 585 persons per square mile. The Las Vegas Valley is approximately 137 kilometers (85 miles) (as measured from the intersection of U.S. Highway 95 and Interstate 15) from the proposed location of the surface facilities. The remainder of Clark County outside the Las Vegas Valley makes up about 90 percent of its geographic area. This part of the county had a 1980 population density of 2.7 persons per square mile (Section 3.6.2.3). The unincorporated town of Indian Springs, located along U.S. Highway 95 in northwest Clark County, is approximately 74 kilometers (46 miles) from the proposed location of the surface facilities, making it the nearest Clark County community. Its 1980 population was estimated to be 1,446 (Section 3.6.2.3).

Sections 3.6.2.2 and 3.6.2.3 present a discussion of the recent and forecast baseline populations for Nye and Clark counties, respectively, and give recent population data for communities nearest the site. Note however, that distances reported in those sections are measured along the existing road network.

The Nevada Test Site (NTS) and Nellis Air Force Range (NAFR) surround the Yucca Mountain site on three sides. About 5,200 persons work but do not reside at the NTS, and several hundred may occasionally remain overnight in Mercury and other NTS locations; however, there are no permanent residences or private property on the NTS or NAFR. The southwest side of the Yucca Mountain site is bounded by land controlled by the Bureau of Land Management and is closed to permanent settlement but open to public access.

The potential radiation doses for the public residing within 80 kilometers (50 miles) of the repository site have been estimated for postulated accidents during repository operations (Jackson et al., 1984). The population within 80 kilometers (50 miles) of the proposed repository location was conservatively estimated to be 19,908, by identifying the counties within that radius and dividing the 1980 county population by the county area to obtain the county population density. Once county population densities were determined, the county area within the 80-kilometer (50-mile) radius was multiplied by that county's density to estimate population. The results for each county were then summed. If population centers (i.e., cities or unincorporated places) are accounted for, the population within 80 kilometers (50 miles) of the proposed repository is estimated to be 11,674 (Morales, 1985). The worst-case accident-related single exposure to the maximally exposed individual, assumed to be located approximately 4 kilometers (2.5 miles) southwest of the surface facilities was estimated to be 0.055 rem (0.068 rem 50-year dose commitment). The same accident would result in an estimated worst-case population dose commitment of 110 man-rem to a population of 19,908 within 80 kilometers (50 miles) of the repository site. Using estimates of natural radiation in granite from DOE (1980a), an estimate of the release of natural radioactivity from the volcanic rocks of the Yucca

Mountain site during construction can be calculated. Construction of a repository would result in an annual effective whole-body dose for a member of the general population of less than 0.05 millirem. Natural background radiation from all sources contributes an individual whole-body equivalent dose of 0.09 rem per year (Jackson et al., 1984). For a discussion of applicable dose limits, refer to sections 6.2.2.1 and 6.4.1. For discussions of potential operational radiation exposures, see Section 6.4.1.

Assumptions and data uncertainties

Long-term changes in population density and distribution are difficult to predict. For example, increased employment opportunities at the Yucca Mountain site during repository construction, operation, and decommissioning could result in population increases in the nearby towns that are different than recent settlement patterns of NTS workers (Table 5-26). However, actual settlement patterns would be one element of a socioeconomic monitoring program that would be developed.

6.2.1.2.3 Favorable conditions

- (1) A low population density in the general region of the site.

Evaluation

The Yucca Mountain site is in Nye County, which had a 1980 population density of 0.5 person per square mile (Section 3.6.2.2). This is low in comparison with the 1980 population density of the continental United States, which was 76 persons per square mile. Two counties adjacent to central Nye County, west and east of the site, respectively, are Esmeralda and Lincoln. In these counties the 1980 population densities were 0.2 and 0.4 person per square mile, respectively (DOC, 1981).

Clark County had a 1980 population density of 58.8 persons per square mile. The nearest urban area is the Las Vegas Valley, 137 kilometers (85 miles) to the southeast. This area includes the incorporated cities of Henderson, Las Vegas, and North Las Vegas as well as the unincorporated towns and communities of East Las Vegas, Enterprise, Grandview, Lone Mountain, Paradise, Spring Valley, Sunrise Manor, and Winchester. The Las Vegas Valley had a 1980 population density of 585 persons per square mile. The part of Clark County outside the Las Vegas Valley, about 90 percent of its geographic area, had a 1980 population density of about 2.7 persons per square mile.

Conclusion

The county containing the Yucca Mountain site had a population density of 0.5 person per square mile, which is substantially below the continental U.S. average density of 76 persons per square mile. Two adjacent counties also had population densities well below the U.S. average. Outside the Las Vegas Valley, which is 137 kilometers (85 miles) away, Clark County had a population density of about 2.7 persons per square mile. Therefore, this favorable condition is present at Yucca Mountain.

(2) Remoteness of the site from highly populated areas.

Evaluation

The Yucca Mountain site is in southern Nye County, Nevada (see Figure 3-21). Southern Nye County is bordered on the east by Clark and Lincoln counties and on the west by Esmeralda County. Borders of these counties are about 68 to 48 kilometers (42 to 30 miles) from the proposed location of the surface facilities. In 1980, neither Lincoln County nor Esmeralda County contained any highly populated areas. Since neither the incorporated city (Gabbs) nor the census designated place (Tonopah) in Nye County had populations greater than or equal to 2,500 in 1980, neither are considered highly populated areas for purposes of the evaluation of this guideline. Gabbs is about 248 kilometers (154 miles) to the northwest, and Tonopah is about 153 kilometers (95 miles) to the northwest. The incorporated city of Caliente in Lincoln County is not considered a highly populated area. The nearest highly populated area is the Las Vegas Valley in Clark County, approximately 137 kilometers (85 miles) southeast of the proposed location of the surface facilities.

The unincorporated towns of Amargosa Valley and Beatty lie closest to the Yucca Mountain site, at distances of 23 kilometers (14 miles, at the nearest population concentration) and 31 kilometers (19 miles), respectively. U.S. Bureau of the Census population estimates for these towns are not available. Beatty had an estimated population of 800 (Smith and Coogan, 1984). Approximately 45 people were concentrated along U.S. Highway 95 in the Amargosa Valley community formerly called Lathrop Wells; another 1,500 persons were located about 37 kilometers (23 miles) south of U.S. Highway 95 in the Amargosa Farm area; and approximately 280 persons lived at the American Borate housing complex on Nevada State Route 373 about 45 kilometers (28 miles) south of the surface facilities location (population data from Smith and Coogan, 1984). These are not considered highly populated areas.

Conclusion

The Yucca Mountain site is remote from any highly populated area. The nearest highly populated area is about 137 kilometers (85 miles) to the southeast of the proposed location of the surface facilities. Therefore, this favorable condition is present at Yucca Mountain.

6.2.1.2.4 Potentially adverse conditions

- (1) High residential, seasonal, or daytime population density within the projected site boundaries.

Evaluation

The surface facilities for a repository at Yucca Mountain would be located in the center of an uninhabited area with a radius of at least 10 kilometers (6.2 miles). Other than the work force currently engaged in preliminary site investigations at Yucca Mountain as part of the Nevada

Nuclear Waste Storage Investigations Project, there is presently no daytime or seasonal use of the area.

Conclusion

The projected boundaries of the Yucca Mountain site (see Figure 2-1) presently contain no residential or daytime population, except for those daytime personnel associated with ongoing investigations of the site for a geologic repository. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

- (2) Proximity of the site to highly populated areas, or to areas having at least 1,000 individuals in an area 1 mile by 1 mile as defined by the most recent decennial count of the U.S. census.

Evaluation

The nearest highly populated area is the Las Vegas Valley about 137 kilometers (85 miles) to the southeast of Yucca Mountain. This is also the nearest area 1 mile by 1 mile having a population of at least 1,000 individuals (Clark County Department of Comprehensive Planning, 1983).

Conclusion

The Yucca Mountain site is about 137 kilometers (85 miles) away from the nearest highly populated area. It is equally remote from any area having at least 1,000 individuals in an area 1 mile by 1 mile as defined by the 1980 census. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

6.2.1.2.5 Disqualifying conditions

There are three disqualifying conditions with regard to population density and distribution. To avoid repetition, the disqualifying conditions (stated below) are evaluated together. Separate conclusions are given for each disqualifying condition.

A site shall be disqualified if:

- (1) Any surface facility of a repository would be located in a highly populated area; or
- (2) Any surface facility of a repository would be located adjacent to an area 1 mile by 1 mile having a population of not less than 1,000 individuals as enumerated by the most recent U.S. census; or
- (3) The DOE could not develop an emergency preparedness program which meets the requirements specified in DOE Order 5500.3 (Reactor and Non-Reactor Facility Emergency Planning, Preparedness, and Response Program for Department of Energy

Operations) and related guides or, when issued by the NRC in
10 CFR Part 60, Subpart I, "Emergency Planning Criteria."

Evaluation

There are no residents within 10 kilometers (6.2 miles) of the Yucca Mountain site. The nearest highly populated area is the Las Vegas Valley at a distance of 137 kilometers (85 miles); this is also the distance to the nearest area 1 mile by 1 mile with a population of more than 1,000 persons.

The U.S. Department of Energy (DOE) in cooperation with the State of Nevada has produced an emergency preparedness plan and notification procedures (State of Nevada, Department of Human Resources, 1983; DOE/NVO, 1985) that covers loss of control of radioactive materials leading to a hazard or potential hazard to public health, safety, or property. This plan identifies agencies and individuals to be notified in the event of a radiological emergency. It provides guidance for the plan participants and establishes procedures for requesting and providing assistance.

Conclusion for disqualifying condition 1

The nearest highly populated area is about 137 kilometers (85 miles) from the proposed location of the surface facilities at Yucca Mountain. Consequently, surface facilities at Yucca Mountain would not be located in a highly populated area. Therefore, the evidence supports a finding that the site is not disqualified on the basis of that evidence and is not likely to be disqualified (level 2).

Conclusion for disqualifying condition 2

The Yucca Mountain site is not adjacent to any area 1 mile by 1 mile having a population of 1,000 or more. The nearest such area is about 137 kilometers (85 miles) by air to the southeast. Therefore, the evidence supports a finding that the site is not disqualified on the basis of that evidence and is not likely to be disqualified (level 2).

Conclusion for disqualifying condition 3

Preparation of an emergency preparedness plan for Yucca Mountain should present no problems; the DOE has already prepared such a plan for the Nevada Test Site and has worked with the State of Nevada to establish a plan for the State. Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is disqualified (level 1).

6.2.1.2.6 Evaluation and conclusion for the qualifying condition on the population density and distribution guideline

Evaluation

The nearest highly populated area, according to 1980 census information, is in the Las Vegas Valley of Clark County which is 137 kilometers (85 miles) from the proposed location of the surface facilities at the Yucca Mountain

site. Preliminary calculations of radiation doses from worst-case single accidental exposure give a total-body dose of 0.055 (0.068 rem 50-year dose commitment) for the maximally exposed individual, who is assumed to be 4 kilometers (2.5 miles) from the surface facility (Jackson et al., 1984). For comparison, these doses are well below the dose limit from 10 CFR Part 20 (1984) of 0.5 rem per year for the total-body dose to a individual in an unrestricted area. The worst-case population dose for the same set of accidents is estimated at 110 man-rem to a conservatively estimated population of 19,908 within 80 kilometers (50 miles) of the potential repository site. The natural background sources contribute an individual total-body dose commitment of 0.09 rem per year and an annual whole-body population dose commitment of about 1,790 man-rem to the same 19,908 people (Jackson et al., 1984). Estimated releases under normal repository operations (for a generic repository) are shown in Section 6.4.1 to produce concentrations well below the maximum permissible concentrations.

Conclusion

The site is in an area of extremely low population density, remote from any highly populated areas. Normal repository operations are not expected to allow releases that exceed requirements. Preliminary calculations indicate that even the expected worst-case radiological dose will not exceed the limits of 10 CFR 960.5-1(a)(1) (1984) and will be negligible when compared with the background-radiation dose. Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition for population density and distribution (level 3).

6.2.1.3 Preclosure site ownership and control (10 CFR 960.5-2-2)

6.2.1.3.1 Introduction

The qualifying condition for this guideline is as follows:

The site shall be located on land for which the DOE can obtain, in accordance with the requirements of 10 CFR 60.121, ownership, surface and subsurface rights, and control of access that are required in order that surface and subsurface activities during repository operation and closure will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1).

This site ownership and control technical guideline is the second of four preclosure guidelines concerned with preclosure radiological safety. The objective is to ensure that the U.S. Department of Energy can obtain land ownership, in accordance with the requirements of 10 CFR 60.121 (1983), and minimize the risk of releases to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1).

The guideline consists of one favorable condition, one potentially adverse condition, and one qualifying condition. A summary of the evaluations presented below is given in Table 6-4.

Table 6-4. Summary of analyses for Section 6.2.1.3; preclosure site ownership and control
(10 CFR 960.5-2-2)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITION	
Present ownership and control of land and all surface and subsurface mineral and water rights by the DOE.	The evidence indicates that this favorable condition is not present at Yucca Mountain: the DOE presently does not exercise jurisdiction and control over all of the land that would make up the site.
POTENTIALLY ADVERSE CONDITION	
Projected land-ownership conflicts that cannot be successfully resolved through voluntary purchase-sell agreements, nondisputed agency-to-agency transfers of title, or Federal condemnation proceedings.	The evidence indicates that this potentially adverse condition is present at Yucca Mountain: withdrawal action is necessary in order for the DOE to obtain jurisdiction and control over a portion of the site.
QUALIFYING CONDITION	
The site shall be located on land for which the DOE can obtain, in accordance with the requirements of 10 CFR 60.121, ownership, surface and subsurface rights, and control of access that are required in order that surface and subsurface activities during repository operation and closure will not be likely to lead to radionuclide release to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1).	Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): the portions of the site not presently under DOE jurisdiction are Federal land; the DOE has a plan to obtain control through inter-agency transfer. Surface and subsurface activities are unlikely to lead to radionuclide releases in excess of the regulatory limits.

6.2.1.3.2 Data relevant to the evaluation

The Yucca Mountain site is wholly on federally owned land not currently restricted by environmental land-use considerations. However, as explained below, three different agencies currently have jurisdiction and control over portions of the site. The eastern portion of the site is within the boundaries of the Nevada Test Site (NTS) under the control of the U.S. Department of Energy (DOE). The northwestern portion is on the Nellis Air Force Range (NAFR) under the control of the U.S. Department of the Air Force (DAF). The southwestern portion is on land in the public domain under the jurisdiction of the Bureau of Land Management (BLM) of the Department of the Interior (DOI). Figure 3-1 shows the location of these segments.

Nevada Test Site segment

Pursuant to Public Land Order 2568, December 19, 1961, (DOI, 1961) this land has been withdrawn from all forms of appropriation under the public land laws, including the mining laws, and is under the jurisdiction and control of the DOE. The DOI has jurisdiction and control over "the mineral resources and mineral and vegetable materials" of the land. The DOE has control over all other surface and subsurface rights, including water rights from points of extraction on the land. The private acquisition of any surface or subsurface rights is presently precluded by virtue of the current public land order.

Nellis Air Force Range segment

Withdrawal legislation for the NAFR is currently before Congress. Until such time as this legislation is enacted, the BLM serves as the official protector of the land and custodian of all surface and subsurface rights. Private acquisition of any rights on or in the land is presently precluded pursuant to Section 204 of the Federal Land Policy and Management Act of 1976.

Bureau of Land Management segment

All of this land is in the public domain under the jurisdiction and management of the BLM and has not been segregated from the operation of the public land laws.

All the above lands are currently free and clear of encumbrances arising under lease, right of entry, deed, patent, mortgage, appropriation, prescription, or otherwise (Lutsey and Nichols, 1972). The land use and withdrawal actions necessary for site characterization and for developing a geologic repository are described in a plan developed by the Nevada Nuclear Waste Storage Investigations Project (Richards and Vieth, 1983). The plan contains the actions necessary for land acquisition to meet the requirements of 10 CFR 60.121 (1983).

Assumptions and data uncertainties

Uncertainties about site ownership and control involve interagency negotiations with the DAF and the BLM over land withdrawal and restrictions. The DOE has control over water rights from points of extraction on the NTS. It

is possible that superior rights to the water in the same underground source may apply to a point of extraction located outside the NTS boundaries. The significance of this issue would depend on superior rights, and a comparison of the amount of water needed to construct and operate the repository to the amount available for extraction from the underground source. This issue will be resolved prior to the commencement of site characterization.

6.2.1.3.3 Favorable condition

Present ownership and control of land and all surface and subsurface mineral and water rights by the DOE.

Evaluation

Control of the land where the potential repository site is located currently resides with the U.S. Department of Energy (DOE) (the Nevada Test Site portion), the U.S. Department of the Air Force (DAF) (the Nellis Air Force Range portion), and the Bureau of Land Management (BLM). Permanent transfer of the required areas to the DOE, including all surface and subsurface rights, would require Congressional approval and could be implemented in accordance with the plan for land use and withdrawal prepared by the Nevada Nuclear Waste Storage Investigations Project.

Conclusion

Presently the DOE has jurisdiction over only a portion of the Yucca Mountain site; the remaining portions are controlled by the DAF and the BLM. Therefore, the evidence indicates that this favorable condition is not present at Yucca Mountain.

6.2.1.3.4 Potentially adverse condition

Projected land-ownership conflicts that cannot be successfully resolved through voluntary purchase-sell agreements, nondisputed agency-to-agency transfers of title, or Federal condemnation proceedings.

Evaluation

While one portion of the Yucca Mountain site lies within the Nevada Test Site (NTS) and already is under the jurisdiction and control of the U.S. Department of Energy, the site also includes tracts of land under the jurisdiction of the U.S. Department of the Air Force (DAF) and the Bureau of Land Management. The air space above the DAF portion is a small, remote section of the Nellis Air Force Range which is used as a flight corridor for military aircraft, and the BLM portion is a tract immediately adjacent to the already restricted lands of the NAFR and the NTS on which no other activities are presently occurring and no privately held rights or encumbrances have been identified as existing. Withdrawal of the BLM portion from the public domain and transfer of control over the DAF portion are necessary for the DOE to

obtain jurisdiction and control over the entire site (information from the land use and withdrawal action plan by Richards and Vieth (1983) cited in Section 6.2.1.3.2).

Conclusion

Withdrawal action is necessary for the DOE to obtain jurisdiction and control over the entire site. Therefore, the evidence indicates that this potentially adverse condition is present at Yucca Mountain. However, in view of the absence of conflicts over land use for this portion, no impediments to the obtaining of control by the DOE are projected.

6.2.1.3.5 Evaluation and conclusion for the qualifying condition on the preclosure site ownership and control guideline

Evaluation

Control of the Yucca Mountain site presently resides with the U.S. Department of Energy (DOE) (the eastern portion on the Nevada Test Site), the U.S. Department of the Air Force (DAF) (the northwestern portion on the Nellis Air Force Range), and the Bureau of Land Management (BLM) (the southeastern portion). The Nevada Nuclear Waste Storage Investigations Project developed a land use and withdrawal plan for the DOE to acquire jurisdiction over the necessary land from the BLM and DAF. No existing privately held rights or encumbrances, which would necessitate government purchase or condemnation action, have been identified for any portion of the site. The implementation of Congressional action necessary for the permanent transfer of title to the DOE has been deferred pending the selection of a site for a repository. A plan to control and limit access to the Yucca Mountain site during the operation and closure of a repository will be prepared in accordance with DOE policies and procedures limiting access to restricted areas. No problems are expected in meeting the applicable safety requirements for radioactive releases to unrestricted areas (Section 6.2.1.2.6).

Conclusion

The plan by which the DOE would acquire jurisdiction and control over all surface and subsurface rights for the Yucca Mountain site will be implemented if the Yucca Mountain site is selected for a repository. No impediments to eventual complete ownership and control by the DOE have been identified. Surface and subsurface activities during repository operation and closure are not expected to lead to releases exceeding the requirements specified in Section 960.5-1(a)(1). Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition for preclosure site ownership and control (level 3).

6.2.1.4 Meteorology (10 CFR 960.5-2-3)

6.2.1.4.1 Introduction

The qualifying condition for this guideline is as follows:

The site shall be located such that expected meteorological conditions during repository operation and closure will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1).

The meteorology technical guideline addresses the concern that radioactive material released during repository operations and closure could be transported to an unrestricted area. The principal objective of this preclosure guideline is to ensure that the meteorological conditions at the proposed site are favorable for the atmospheric dispersion of any airborne radionuclides that might be released from the repository and to ensure compliance with the system guideline for preclosure radiological safety. Also of concern is the potential for extreme weather phenomena that could affect the operation and safety of the repository.

The guideline consists of one favorable condition, two potentially adverse conditions, and one qualifying condition. The evaluations presented below are summarized in Table 6-5.

6.2.1.4.2 Data relevant to the evaluation

Long-term meteorological data have not been collected at Yucca Mountain. A weather station was operated from 1956 to 1978 at Yucca Flat, approximately 40 kilometers (25 miles) to the northeast. Data from the station have been compiled for the 10 years from 1962 through 1971 (Bowen and Egami, 1983), and upper air data have been compiled for the 7 years from 1957 through 1964 (Quiring, 1968). Since mid-1982, a meteorological measurement system consisting of two monitoring stations, one near the ridge and one to the east of Yucca Mountain (both instrumented at levels 10 and 3 meters (33 and 10 feet) above the ground, has been operated for the Nevada Nuclear Waste Storage Investigations Project by the Desert Research Institute. Data from this system are available (Church et al., 1984). The National Weather Service has been recording meteorological data since 1914 at Beatty, approximately 31 kilometers (19 miles) west of Yucca Mountain. These data are on file at the National Oceanic and Atmospheric Administration, National Climatic Center, Asheville, North Carolina.

Statistical information on severe weather and storms in southern Nevada is contained in reports by Thom (1963), Pautz (1969), the U.S. Nuclear Regulatory Commission (Henz and Pearl, 1981), Bowen and Egami (1983), Quiring (1983), and Hershfield (1961). Regional atmospheric diffusion and dispersion characteristics are discussed by Bowen and Egami (1983) and Holzworth (1972).

Table 6-5. Summary of analyses for Section 6.2.1.4; meteorology (10 CFR 960.5-2-3)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITION	
Prevailing meteorological conditions such that any radioactive releases to the atmosphere during repository operation and closure would be effectively dispersed, thereby reducing significantly the likelihood of unacceptable exposures to any member of the public in the vicinity of the repository.	The evidence indicates that this favorable condition is present at Yucca Mountain: regional wind flow patterns and atmospheric dispersion characteristics are expected to effectively disperse radioactive releases, if any, and to thereby reduce the likelihood of unacceptable exposures to any member of the public.
POTENTIALLY ADVERSE CONDITIONS	
(1) Prevailing meteorological conditions such that radioactive emissions from repository operation or closure could be preferentially transported toward localities in the vicinity of the repository with higher population densities than are the average for the region.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: surface and high-level winds toward the population center in the Las Vegas urban area (about 137 kilometers (85 miles) away by air) occur less than 12 percent of the time. No preferential transport toward local population centers is expected.
(2) History of extreme weather phenomena--such as hurricanes, tornadoes, severe floods, or severe and frequent winter storms--that could significantly affect repository operation or closure.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: Yucca Mountain has one of the lowest frequencies of extreme weather in the U.S. Extreme weather phenomena occurring in the desert are of such short duration that no significant effects on repository operation or closure are expected.

Table 6-5. Summary of analyses for Section 6.2.1.4; meteorology (10 CFR 960.5-2-3) (continued)

Condition	Department of Energy (DOE) finding
QUALIFYING CONDITION	
<p>The site shall be located such that expected meteorological conditions during repository operation and closure will not be likely to lead to radioactive releases to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1).</p>	<p>Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): good atmospheric dispersion and limited possibility for preferential transport toward population centers are expected; no severe meteorological conditions that would cause radioactive releases greater than regulatory limits are expected.</p>

Data regarding the population centers in the region around Yucca Mountain have been obtained from Smith and Coogan (1984) and Clark County Department of Comprehensive Planning (1983).

Assumptions and data uncertainties

Much of the available meteorological information is not specific to Yucca Mountain. However, the Yucca Flat and Beatty measurement stations are close enough for their data to be representative of the general meteorological conditions at Yucca Mountain. Also, both the Yucca Flat station and the proposed repository surface facilities are located in topographically similar basins, and should experience similar meteorological conditions. Terrain-induced diurnal wind flow patterns are very localized and would not contribute significantly to regional atmospheric dispersion. Upper level wind direction data should adequately reflect the regional-scale winds, which are primarily responsible for long-range transport. The historical information on severe weather and storms has been collected at a limited number of observation stations in the region; the frequency of these phenomena could be slightly underestimated, because of the broad spatial distribution of recording stations. Nonetheless, the frequency or severity of storms probably is not significantly underestimated because the observed frequencies are low throughout the area.

6.2.1.4.3 Favorable condition

Prevailing meteorological conditions such that any radioactive releases to the atmosphere during repository operation and closure would be effectively dispersed, thereby reducing significantly the likelihood of unacceptable exposures to any member of the public in the vicinity of the repository.

Evaluation

Meteorological conditions should provide for effective atmospheric dispersion at the Yucca Mountain site. It is assumed that regional scale patterns are similar to those measured at Yucca Flat. It is recognized that meteorological conditions vary somewhat with altitude and geographic location. High average annual wind speeds of 11.9 kilometers (7.4 miles) per hour have been measured at Yucca Flat over a 10-year period of record (Bowen and Egami, 1983), and high wind speeds, which favor effective dispersion, are also expected at Yucca Mountain. Calculations by Holzworth (1972) indicate that extreme limitations to atmospheric dispersion should rarely occur over the Yucca Mountain area. Isopleths of the mean annual mixing heights show that the region surrounding the proposed site experiences some of the deepest atmospheric mixing layers in the United States, a condition that is favorable to atmospheric mixing and dispersion.

Conclusion

Wind velocities, flow patterns, and atmospheric-diffusion characteristics in the region of the Yucca Mountain site will contribute to the

effective dispersion of airborne radionuclides. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

6.2.1.4.4 Potentially adverse conditions

- (1) Prevailing meteorological conditions such that radioactive emissions from repository operation or closure could be preferentially transported toward localities in the vicinity of the repository with higher population densities than are the average for the region.

Evaluation

Because of the sparse distribution of cities and towns in southern Nevada, establishing a meaningful average population density is difficult. In addition, some of the small towns close to Yucca Mountain may experience population increases if the site is selected for development as a repository. For these reasons, it is prudent to assess the likelihood of preferential atmospheric transport toward the smaller nearby towns as well as the larger cities in the region. The nearest population center to Yucca Mountain is the unincorporated Town of Amargosa Valley, whose residents are spread out in numerous small settlements within its estimated 1,036 square kilometers (400 square miles) (Section 3.6.4.1.1). Major population concentrations are located in the community formerly called Lathrop Wells and now known as Amargosa Valley, approximately 23 kilometers (14 miles) to the south; the Amargosa Farm Area, approximately 37 kilometers (23 miles) to the south; and the American Borate housing complex roughly 45 kilometers (28 miles) to the south. Population of these areas in 1984 was estimated to be 45, 1,500, and 280, respectively (Smith and Coogan, 1984). An estimate of the total population in the unincorporated town is not available (see Section 3.6.2.2). The nearest highly populated area to Yucca Mountain is the Las Vegas Valley with a 1980 population of 443,730 (Clark County Department of Comprehensive Planning, 1983). It is located approximately 137 kilometers (85 miles) by air southeast of the site. The town of Beatty, with a population of 800 (Smith and Coogan, 1984), is approximately 31 kilometers (19 miles) by air west of the site.

Wind speed and direction data have been compiled for the station located at Yucca Flat for the period 1961-1978 (DOC, 1986). Although these data reflect terrain influences specific to Yucca Flat, the setting at Yucca Mountain is similar enough to warrant use of the Yucca Flat data for this analysis. The general north-south alignment of the basin in which the repository would be located will most likely be the major influence on surface wind patterns, as is the case for Yucca Flat. Winds from the south dominate the distribution, occurring 14 percent of the time on an annual basis. Winds from the north are also quite frequent, occurring just over 11 percent of the time, again on an annual basis. Seasonally, southerly winds are most common in the spring and summer months, shifting to a northerly dominance in fall and winter months. Northwest winds (which would transport material to the southeast toward Las Vegas) have occurred less than 10 percent of the time on the average. Winds that could transport material to the west toward Beatty have been observed only 5 percent of the time.

A 7-year record of upper-air data from Yucca Flat (Quiring, 1968) was used to further evaluate the meteorological conditions that might transport airborne radionuclides toward population centers. Wind-direction data from two heights, 1,500 and 1,800 meters (5,000 and 6,000 feet) above mean sea level, were used in this assessment. Data from these levels are considered to be indicative of atmospheric-transport winds beyond the influence of local terrain features (i.e., Yucca Mountain). At 1,500 meters (5,000 feet), winds from the entire northwest sector (285 to 345°), which could transport airborne radionuclides toward the Las Vegas Valley, occurred only 11 percent of the time annually. At 1,800 meters (6,000 feet), winds from the northwest were observed approximately 10 percent of the time annually. Winds from the east (which would transport material toward Beatty) occurred approximately 2 percent of the time at Yucca Flat at both 1,500 and 1,800 meters (5,000 and 6,000 feet). The wind blows toward the south approximately 20 percent of the time at the 1,500-meter (5,000-foot) level and 14 percent of the time at the 1,800-meter (6,000-foot) level.

Conclusion

Regional meteorological flow patterns will not cause the preferential transport of airborne radionuclides from the site toward localities with higher population densities than are the average for the region. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(2) History of extreme weather phenomena--such as hurricanes, tornadoes, severe floods, or severe and frequent winter storms--that could significantly affect repository operation or closure.

Evaluation

The severe weather recorded in the area of the Yucca Mountain site includes high winds, thunderstorms, tornadoes, hail, and sandstorms, but occurrences of these extreme weather phenomena are infrequent. Thunderstorms occur on 16 percent of the days in July and August, but only occur an average of 5 percent of the days annually at Yucca Flat (Bowen and Egami, 1983). Severe thunderstorms create a potential for flash flooding, but they generally do not last longer than an hour according to Bowen and Egami (1983). Discussions of the drainage control measures that are expected to provide adequate protection from flood damage for Yucca Mountain are included in sections 6.3.3.1 and 6.3.3.3. High winds may occur in the area, accompanying winter storm fronts or thunderstorms. Wind speeds in excess of 100 kilometers (60 miles) per hour can be expected to occur on a 100-year return period (Quiring, 1968). However, such velocities are not common; monthly average wind speeds for Yucca Flat do not deviate significantly from the average annual wind speed. See Section 3.4.3 for further discussion of weather conditions. Significant lightning strikes have averaged only 18 per year for the entire State of Nevada (Henz and Pearl, 1981). Tornadoes are very rare in Nevada, with the probability of a tornado striking Yucca Mountain calculated to be 7.5×10^{-4} per year or once in 1,333 years (Thom, 1963). Hail with a diameter of 1.9 centimeters (0.75 inch) or larger was observed on 7 days in Nevada between 1955 and 1967 (Pautz, 1969). Sandstorms are common in Nevada but rarely severe enough to be expected to affect

repository operation or closure. The annual average snowfall at Yucca Flat is 21 centimeters (8.3 inches) (Bowen and Egami, 1983). The statistical maximum 24-hour precipitation for 10- and 100-year storms for Yucca Flat is 38 and 57 millimeters (1.50 and 2.25 inches), respectively (Hershfield, 1961). Quiring (1983) provides more recent data for Yucca Flat on the 24-hour precipitation for 10- and 100-year events of 45 and 68 millimeters (1.8 and 2.7 inches), respectively. The above frequencies of occurrence of severe weather are among the lowest in the United States (Hershfield, 1961). Furthermore, the magnitudes of these phenomena are not unusually large.

Conclusion

Available statistical summaries reveal that the region surrounding Yucca Mountain has one of the lowest frequencies of extreme weather in the United States. Extreme weather phenomena are neither frequent enough nor severe enough to be expected to significantly affect the safety of repository operation or closure. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

6.2.1.4.5 Evaluation and conclusion for the qualifying condition on the meteorology guideline

Evaluation

Records of meteorological data for Yucca Flat and Beatty, combined with statistical evaluations of severe-weather phenomena, indicate that occurrences of severe weather are infrequent and would not be expected to significantly affect repository construction, operation, or closure. Deep atmospheric mixing in the region will contribute to the effective dispersion of airborne radionuclides if any are released from the repository. Prevailing wind directions are not likely to cause preferential transport of airborne radionuclides toward regional population centers. Extreme weather phenomena are rare in the vicinity of Yucca Mountain, except for occasional heavy precipitation of short duration that may cause localized flash flooding (Section 6.3.3.3). However, standard drainage control measures are considered adequate to ensure that the public health and safety are protected and that no radionuclide releases to an unrestricted area greater than those allowable under applicable regulations and standards are likely.

Conclusion

No severe meteorological conditions have been recorded or are expected to occur in the region that would contribute to radionuclide releases to an unrestricted area greater than those allowable under regulatory limits.

6.2.1.5 Offsite installations and operations (10 CFR 960.5-2-4)

6.2.1.5.1 Introduction

The qualifying condition for this guideline is as follows:

The site shall be located such that present projected effects from nearby industrial, transportation, and military installations and operations, including atomic energy defense activities, (1) will not significantly affect repository siting, construction, operation, closure, or decommissioning or can be accommodated by engineering measures and (2), when considered together with emissions from repository operation and closure, will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1).

The offsite installations and operations technical guideline is the last of the four preclosure technical guidelines concerned with preclosure radiological safety. The objectives of this guideline are (1) to ensure that the impacts of any nearby industrial, transportation, military, and atomic energy defense installations and operations on repository siting, construction, operation, closure, and decommissioning are adequately considered and (2) to ensure that any radionuclide emissions from such installations when combined with preclosure emissions from the repository, would not lead to total radiological exposures in any unrestricted area in excess of regulatory limits.

This guideline consists of one favorable condition, two potentially adverse conditions, one disqualifying condition, and one qualifying condition. The evaluations presented below are summarized in Table 6-6.

6.2.1.5.2 Data relevant to the evaluation

The installations and operations adjacent to Yucca Mountain are the Nevada Test Site (NTS) on the east and the Nellis Air Force Range (NAFR) to the northwest. The primary mission of the NTS is the underground testing of nuclear devices. The size of nuclear tests is currently limited to a maximum yield of 150 kilotons by the Threshold Test Ban Treaty and the Treaty on Underground Nuclear Explosions for Peaceful Purposes (Vortman, 1979; ERDA, 1977), but the capability to return to larger or former yields must be retained. The number of announced nuclear tests has been averaging about 20 per year and is expected to remain at that level for the foreseeable future (DOE/NVO, 1983b). At present, tests are conducted at Yucca Flat, Rainier Mesa, and Pahute Mesa (Figure 6-1). The size of tests is restricted by the potential for damage to offsite facilities from ground motion; Yucca Flat has a yield limit of about 250 kilotons and Pahute Mesa has a 1,400-kiloton limit (Vortman, 1979). Both of these limits are well above the current yield limits specified by treaty. The Buckboard area, a past area of testing that may be used again, has a 700-kiloton yield limit (Vortman, 1979). The yield limit for Mid Valley, a future potential test area, is likely to be similar to that for Yucca Flat.

Table 6-6. Summary of analyses for Section 6.2.1.5; offsite installations and operations
(10 CFR 960.5-2-4)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITION	
Absence of contributing radioactive releases from other nuclear installations and operations that must be considered under the requirements of 40 CFR Part 191, Subpart A.	The evidence indicates that this favorable condition is present at Yucca Mountain: there are no nuclear installations or operations regulated by 40 CFR Part 191 in the region.
POTENTIALLY ADVERSE CONDITIONS	
(1) The presence of nearby potentially hazardous installations or operations that could adversely affect repository operation or closure.	The evidence indicates that this potentially adverse condition is present at Yucca Mountain: the potential exists for short-term interruptions of repository activities due to weapons tests and the remote possibility of interruptions or releases caused by an aircraft crash.
(2) Presence of other nuclear installations and operations subject to the requirements of 40 CFR Part 190 or 40 CFR Part 191, Subpart A, with actual or projected releases near the maximum value permissible under those standards.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: there are no nuclear installations or operations regulated by 40 CFR Part 190 or 40 CFR Part 191 in the area.

Table 6-6. Summary of analyses for Section 6.2.1.5; offsite installations and operations
(10 CFR 960.5-2-4) (continued)

Condition	Department of Energy (DOE) finding
QUALIFYING CONDITION	
<p>The site shall be located such that present projected effects from nearby industrial, transportation, and military installations and operations, including atomic energy defense activities, (1) will not significantly affect repository siting, construction, operation, closure, or decommissioning, or can be accommodated by engineering measures and (2), when considered together with emissions from repository operation and closure, will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1).</p>	<p>Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): the potential for short-term interruption of repository activities by weapons tests is not expected to significantly affect repository siting, construction, operation, closure, or decommissioning; releases from underground weapons testing when considered with potential repository emissions, will not be likely to exceed limits for radionuclide releases to unrestricted areas.</p>

Figure 6-1. Past, current, and potential future weapons-testing areas on the Nevada Test Site.

Underground nuclear explosions generate seismic energy; the resulting ground motion is similar to that generated by natural earthquakes. The ground motion produced by underground nuclear explosions has been extensively investigated (ERC, 1974; Vortman, 1979, 1980, 1982, 1983; Vortman and Long 1982a,b). Because of a concern about offsite damage, equations have been developed to predict ground motion from underground nuclear explosions at Pahute Mesa and Yucca Flat, where nuclear tests are routinely conducted (ERC, 1974). These test areas are 40 to 50 kilometers (24 to 33 miles) north and east of Yucca Mountain.

Data from underground nuclear tests conducted since 1971 indicate that the major portion of radioactive emissions from underground nuclear tests are contained (ERDA, 1977). Onsite sampling for airborne tritium and noble gases shows that the average concentrations of tritium and xenon-133 are slightly higher than ambient offsite levels (Scoggins, 1983). The tritium enters the atmosphere by evaporation from soil moisture in and around past experimental areas, from holding ponds that receive water drained from tunnel areas, and from gas seepage. Xenon-133 may be released in small quantities as it seeps upward to the surface from underground detonation points. Postshot reentry drilling operations may release small quantities of radioactive noble gases. However, for four out of the last five 1-year reporting periods, no detectable levels of radioactivity from the underground nuclear-test program were observed by any of the monitoring networks located off the NTS (see discussion under the first potentially adverse condition). The radiological background information is reviewed in Section 3.4.7.

Available data describe upper limits to the radiation doses that accidents at the repository might cause. The potential worst-case accidental radiation dose for the public residing within 80 kilometers (50 miles) of the repository site and the worst-case dose commitment for repository personnel have been estimated (Jackson et al., 1984).

The Nevada Research and Development Area, adjacent to the eastern side of Yucca Mountain, is currently being used for research programs. A program that was evaluated for potential impact on repository construction and operation activities is being conducted at the Engine Maintenance, Assembly, and Disassembly facility (E-MAD). There are 17 spent nuclear fuel assemblies at the E-MAD facility which were used for tests and demonstrations that commenced in 1978. These assemblies are scheduled for removal in May and June of 1986. A detailed safety assessment was issued (DOE/NVO, 1978) identifying the engineered safety features, procedures, and site characteristics that (1) prevent the occurrence of potential accidents, or (2) ensure that the consequences of postulated accidents are either insignificant or adequately mitigated. Evaluations were made of the radiological impacts of normal operations, abnormal operations, and postulated accidents at the E-MAD facility. Analyses were also performed to determine the effects on nuclear criticality safety of the postulated accidents and credible natural phenomena. In the unlikely event of the postulated worst-case fuel-handling accident, the maximum total radiation exposure at the NTS boundary was estimated to be less than 0.001 rem. For comparison, this is well below the whole-body radiation dose limit in unrestricted areas of 0.5 rem per year prescribed by 10 CFR Part 20 (1984).

A commercial low-level waste burial site is located about 31 kilometers (19 miles) west of Yucca Mountain near Beatty. Radiation monitoring is conducted continuously at this site by the U.S. Environmental Protection Agency (Black et al., 1983).

The NAFR is used primarily for aerial bombing and gunnery practice. The Tonopah Test Range, an area of 1,615 square kilometers (600 square miles) in the northwestern part of the NAFR, is used by the DOE primarily for airdrop tests of ballistic shapes (ERDA, 1975). The portion of the range in the immediate vicinity of Yucca Mountain is used only for overflights and provides air access to the northwestern part of the range.

The DOE, through negotiations with the U.S. Air Force (USAF), has established operational restrictions for flights through the air space controlled by the DOE over the NTS. Two small flight corridors were designated in the vicinity of Yucca Mountain. They are R4808W and R4808E. The proposed surface facilities complex will be located within the R4808W corridor. The proposed subsurface facilities will be located adjacent to the west side of the R4808W corridor. Currently R4808E is generally closed to all military aircraft, while R4808W is open to military aircraft upon request. The DOE is interacting with the U.S. Air Force (USAF) to address and resolve all concerns of potential repository impacts on USAF operations in the area. The DOE policy is not to restrict the flight requirements of the USAF operations.

Assumptions and data uncertainties

It is possible that future underground nuclear tests will be conducted on the NTS at locations other than Pahute Mesa, Rainier Mesa, and Yucca Flat. Two possible locations that have been identified are the Buckboard area, which is 23 to 37 kilometers (14 to 23 miles) from Yucca Mountain, and Mid Valley, which is 25 to 30 kilometers (16 to 19 miles) from Yucca Mountain. Vortman (1980) indicated that a given size underground nuclear test in the Buckboard area would produce about the same ground motion as would result from a test of the same size on Pahute Mesa because the rock properties that control ground motion are similar at the two locations. However, the ground motion that would result at Yucca Mountain from Buckboard area tests would be greater than that from tests at Pahute Mesa because the Buckboard area is closer to Yucca Mountain. Mid Valley and Yucca Flat are also likely to produce about the same ground motion from tests the same size. Similarly, tests conducted at Mid Valley would produce greater ground motion at Yucca Mountain than would be caused by tests of the same size at Yucca Flat because Mid Valley is closer to Yucca Mountain.

No new industrial or defense-related activities are planned in the vicinity of Yucca Mountain. The USAF is currently evaluating potential locations for deployment of small intercontinental ballistic missiles, in response to the recommendations of the President's Commission on Strategic Forces. Three modes of deployment are being considered: hard silos, hard mobile launchers with random movement, and hard mobile launchers in a confined area at existing minutemen complexes. The USAF is examining 51 sites in 14 states. Twenty-two of these sites are being considered for hard mobile launchers with random movement, six for mobile launchers in a confined area, and some sites of these two alternatives plus the remaining twenty-four

sites are being considered for hard silo deployment. The NTS is one of the sites currently under preliminary consideration for hard mobile launcher deployment. The USAF is presently evaluating that land area available at the Nevada Test Site for deployment of hardened mobile launchers that will not conflict with existing facilities or approved missions. Potential conflicts have been identified by the DOE and include: a mission conflict with nuclear testing and the DOE requirement to ensure availability of test real estate indefinitely; a mission conflict with future Strategic Defense Initiatives research and development; and severe administrative conflicts on safety, security, scheduling of nuclear tests, communications, airspace restrictions, resources, housing, transportation, and environmental issues. Additional information on the USAF site evaluation process is not expected until early 1986. At present, the limited amount of information available on which areas will be selected, the sites within those areas, and the extent of the land requirements required to support deployment make it impossible to evaluate impacts at this time.

6.2.1.5.3 Favorable condition

Absence of contributing radioactive releases from other nuclear installations and operations that must be considered under the requirements of 40 CFR 191, Subpart A.

Evaluation

Subpart A of 40 CFR Part 191 (1985) applies to radiation doses received by members of the public as a result of the management (except for transportation) and storage of spent nuclear fuel and high-level radioactive waste. The nuclear activities at the NTS are not controlled by Subpart A of 40 CFR Part 191 (1985).

Conclusion

No nearby nuclear installations or operations regulated by Subpart A of 40 CFR Part 191 (1985) exist in the region surrounding the Yucca Mountain site. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

6.2.1.5.4 Potentially adverse conditions

(1) The presence of nearby potentially hazardous installations or operations that could adversely affect repository operation or closure.

Evaluation

The portion of the Nellis Air Force Range (NAFR) near Yucca Mountain is used for military-aircraft flights to and from target areas, although this portion of the NAFR is not a target area. If a repository is built at Yucca Mountain, there may be low-altitude overflights by U.S. Air Force (USAF) air-

craft of trains transporting casks of waste on the proposed rail-spur access route to the site. The effect on a repository of overflights would be increased noise levels and a remote chance of an airplane crash at the site. The U.S. Department of Energy (DOE), through discussions with the USAF is evaluating the potential for possible conflicts between USAF and repository operations, including access routes. No irreconcilable conflicts have been identified in these discussions and a variety of options for minimizing conflicts have been discussed for consideration if further study indicates such actions are required.

The Nevada Research and Development Area adjacent to the eastern side of Yucca Mountain, is currently being used for research programs. There are 17 spent fuel assemblies at the Engine Maintenance, Assembly, and Disassembly (E-MAD) facility; they have been used for tests and demonstrations that began in 1978. These assemblies are scheduled for removal in May/June of 1986. A detailed safety assessment was issued (DOE/NVO, 1978) evaluating the radiological impacts of normal operations, abnormal operations, and postulated accidents at the E-MAD facility. Analyses were also performed to determine the effects on nuclear criticality safety of the postulated accidents and credible natural phenomena. In the unlikely event of the postulated worst-case fuel handling accident, the maximum total radiation exposure at the Nevada Test Site boundary was estimated to be less than 0.001 rem.

The primary mission of the NTS is the underground testing of nuclear weapons. The activities and conditions under which radionuclide releases could occur are described in the the Final Environmental Impact Statement, Nevada Test Site, Nye County, Nevada (ERDA, 1977). Releases from these nuclear activities are governed by DOE Order 5480.1, which include the DOE requirements for radiation protection (DOE, 1980a). Underground repository activities may be temporarily suspended during a nuclear test. This action would be taken as a special precaution for certain underground tests depending on their location in relation to the repository. Because the DOE exercises control over the schedule of activities at the NTS, compatible arrangements for nuclear testing and repository construction-operation activities can be made. The current policy of the DOE Nevada Operations Office requires the removal of workers from underground mines within about 80 kilometers (50 miles) of an underground test of approximately 80 kilotons or larger (Vortman, 1980). The removal of workers from the underground facility would be a standard industrial practice to guarantee the safety of workers. Other preparations might include the purging of contaminated hot-cell atmospheres or the securing of waste disposal containers and spent fuel assemblies. Plans for the evacuation of facilities that are judged to be particularly hazardous could also be developed.

The Environmental Protection Agency conducts an Offsite Radiological Safety Program, which includes monitoring of the NTS. This program uses several monitoring networks for measuring radioactivity and radiation levels in the site environs. Radiation from the underground testing at the NTS is not expected to endanger repository-worker safety or adversely affect repository activities. On very infrequent occasions, underground nuclear explosions at the NTS release small amounts of radioactivity to the atmosphere. Data for airborne radionuclides from the NTS detected off the site from 1974 through 1983 are provided in Table 6-7. As shown in Table 6-7, no detectable levels of radioactivity from the underground tests were observed

Table 6-7. Airborne radionuclides from the Nevada Test Site detected off the site, 1974 through 1983

Year	Station Detecting Radionuclides ^a	Radionuclides detected	Highest calculated individual whole-body dose ^b (microrem)	Population dose ^c (man-rem)
1974 ^d	Beatty,* Diablo, Indian Springs	Xe-133	2	0.003
1975 ^e	Beatty,* Diablo, Hiko, Indian Springs, Las Vegas	Xe-133, Kr-85, H-3	2.1	0.00065
1976 ^f	Death Valley Junction*	H-3	1.3	0.00078
1977 ^g	Beatty,* Diablo, Hiko, Las Vegas, Tonopah	Xe-133	2.5	0.0013
1978 ^h	Diablo, Indian Springs*	Xe-133, H-3	6.2	0.0087
1979 ⁱ	None	None	0	0
1980 ^j	Lathrop Wells* (Amargosa Valley)	Xe-133, Xe-135	11	0.00072
1981 ^k	None	None	0	0
1982 ^l	None	None	0	0
1983 ^m	None	None	0	0

^aAll communities in Nevada. Those communities marked with an asterisk (*) are within 80 km (50 miles) of the proposed repository surface facilities complex.

^bDose calculated from the largest amount detected (not necessarily within the 80-km (50-mile) radius. For perspective, the largest dose listed (11.0 microrem or 11.0×10^{-6} rem) is only 0.005 percent of the average annual dose an individual in this area receives from naturally occurring internal and external radiation and 0.001 percent of the Nuclear Regulatory Commission radiation protection standard of 0.5 rem per year (10 CFR Part 20, 1984).

^cPopulation dose calculated using the radionuclide detected and the population within the 80-km (50-mile) circle. The population dose, sometimes referred to as collective dose, is simply a summation of the doses received by individuals in an exposed population. For example, if each member of a population of 100 individuals received a dose of 0.1 rem, the population dose would be 10 man-rem. These population doses are extremely small compared with the annual population dose of 400 man-rem from naturally occurring radiation received by the 4,600 people living within the area analyzed (Patzner et al., 1984).

^dData from EPA (1975).

^eData from EPA (1976).

^fData from EPA (1977).

^gData from Grossman (1978).

^hData from Grossman (1979).

ⁱData from Potter et al. (1980).

^jData from Smith et al. (1981).

^kData from Black et al. (1982).

^lData from Black et al. (1983).

^mData from Patzner et al. (1984).

outside the NTS boundaries during four of the past five 1-year monitoring periods. Section 3.4.7.2 presents discussions of dose assessments for a hypothetical individual at the NTS boundary, and shows that assuming this individual receives a 1-year intake of air and water with radionuclide concentrations measured on the site, the dose represents less than 0.5 percent increase over natural background for total body and lungs, and less than 1.5 percent increase for bone. Regulations for the containment of radiation from underground nuclear tests are very stringent (ERDA, 1977).

If a repository is built at Yucca Mountain, it must be built to withstand the ground motion from natural earthquakes and from underground nuclear explosions. It should be recognized that explosion-induced aftershocks are generally confined to within 14 kilometers (8.7 miles) of the site of explosion (Hamilton et al., 1971). An acceleration-prediction equation has been developed on the basis of experimental data from 21 tests at Pahute Mesa (Vortman, 1980). The equation predicts that the mean peak vector ground acceleration at Yucca Mountain from underground nuclear explosions at the maximum allowable yield (based on offsite damage restrictions) would be 0.061g, resulting from a 700-kiloton test at the Buckboard area. The mean ground acceleration plus 3 standard deviations (99 percent of all probable values) is 0.32g, based on the preceding value of predicted mean peak vector ground acceleration. This is a more conservative approach than that used for nuclear-reactor siting, which requires only mean ground acceleration plus 1 standard deviation (68 percent of all probable values) (Vortman, 1980).

A worst-case repository accident scenario resulting from an underground nuclear explosion considered by Jackson et al. (1984) estimates the consequences of a surface acceleration of 0.32g at the repository site. The scenario included an assumption that the acceleration was accompanied by several unlikely failures in the repository surface facilities. It assumed that, through human error, the hot-cell atmosphere had not been purged, an electrical failure occurred, and pressure regulation in the hot cell was lost. The hot-cell seals were assumed to fail, and scale from fuel rods and fission gases were assumed to be released into the waste-preparation facility. The contaminated air was assumed to eventually be vented through a roughing filter and two banks of high-efficiency particulate air filters to the stack. The probability of this event was calculated to be less than 1.0×10^{-3} per year. Calculations for the maximum individual 50-year total-body dose commitment for this scenario give 2.4×10^{-4} rem at a postulated exclusion boundary about 4 kilometers (2.5 miles) from the facility. For comparison, the individual whole-body dose limit for normal operations in unrestricted areas is 0.5 rem per year (10 CFR Part 20, 1984). The general population, conservatively estimated for this evaluation at 19,908 within 80 kilometers (50 miles) of the potential repository site, would receive 3.1×10^{-3} man-rem. These upper limits to doses caused by the surface acceleration and multiple failures are much smaller than doses from natural background. Natural background sources contribute an individual total-body equivalent dose of 0.09 rem per year and an annual external whole-body population dose commitment of about 1,790 man-rem to the same 19,908 people (Jackson et al., 1984). The population within 80 kilometers (50 miles) of the repository was conservatively estimated by identifying the counties within an 80-kilometer (50-mile) radius of the proposed repository, and dividing the 1980 county population by the county area to obtain the

population density (see Section 6.2.1.2). If population centers (i.e., cities or unincorporated places) are accounted for, the population within 80 kilometers (50 miles) of the proposed repository is estimated to be 11,674 (Morales, 1985).

Calculations for the worker dose commitments from this same accident (Jackson et al., 1984) indicate that the total-body 50-year dose commitment received by an individual worker would be 0.37 rem. Whole-body occupational dose limits for individual workers for routine operations in 10 CFR Part 20 (1984) are 5 rem per year or 3 rem per quarter. The whole-body equivalent dose received by an individual worker from background sources is about 0.09 rem per year.

Conclusion

Present or projected activities on the NTS and the NAFR should have no significant adverse impacts on a repository at Yucca Mountain. There is a very remote possibility of a radioactive release caused by the crash of a military aircraft from Nellis Air Force Range. The Nevada Test Site could, however, adversely affect the repository in two minor ways. The removal of workers from the underground portion of the repository during certain nuclear tests will cause a minor disruption in repository activities. There is also a very unlikely possibility that an underground nuclear test at the NTS could release sufficient radioactivity to the atmosphere to affect repository activities. Therefore, the evidence indicates that this potentially adverse condition is present at Yucca Mountain.

(2) Presence of other nuclear installations and operations, subject to the requirements of 40 CFR Part 190 or 40 CFR 191, Subpart A, with actual or projected releases near the maximum value permissible under those standards.

Evaluation

The provisions of 40 CFR Part 190 (1982) apply to radiation doses received by members of the public and to radioactive materials introduced into the general environment as a result of operations which are a part of the nuclear fuel cycle. The nuclear fuel cycle operations covered by 40 CFR 190 (1982) are those associated with the nuclear generation of electrical power for public use but does not include operations at a waste disposal site. Subpart A of 40 CFR Part 191 (1985) applies to radiation doses received by members of the public as a result of the management (except for transportation) and storage of spent nuclear fuel and high-level radioactive waste, to the extent that these operations are not subject to the provisions of 40 CFR Part 190 (1982).

Neither regulation applies to the nuclear-weapons testing at the NTS or to the low-level radioactive waste disposal site near Beatty, 31 kilometers (19 miles) west of Yucca Mountain.

Conclusion

There are no nuclear installations or operations in the vicinity of the Yucca Mountain site with potential releases governed by 40 CFR Part 190

(1982) or 40 CFR 191, Subpart A (1985). Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

6.2.1.5.5 Disqualifying condition

A site shall be disqualified if atomic energy defense activities in proximity to the site are expected to conflict irreconcilably with repository siting, construction, operation, closure, or decommissioning.

Evaluation

The Yucca Mountain site is over 40 kilometers (25 miles) from the nearest area presently used for underground nuclear detonations. Potential areas for future underground nuclear testing that are closer to the Yucca Mountain site are shown in Figure 6-1, and none are closer than approximately 23 kilometers (14 miles). The Yucca Mountain site is not in an area where surface activities are normally suspended and individuals removed as a routine precautionary measure during underground testing activities elsewhere at the Nevada Test Site (NTS). However, the current policy of the U.S. Department of Energy Nevada Operations Office requires the removal of workers from underground mines within about 80 kilometers (50 miles) of an underground test of approximately 80 kilotons or larger (Vortman, 1980) and for certain other tests if there is larger than normal uncertainty in the effects of the detonation. Such a policy would have an effect during the siting, construction, operation, closure, and decommissioning of the repository.

Extensive studies of ground motion induced by underground nuclear explosions have been used to investigate the potential conflict between atomic energy defense activities and a repository at Yucca Mountain. Fourteen mines within 50 kilometers (31 miles) of the NTS boundaries have been under surveillance by the U.S. Bureau of Mines to determine the nature and the extent of damage from ground motion induced by underground nuclear tests. No damage to offsite mines had been reported through 1977 (ERDA, 1977), and more recent information is not available.

A nuclear test at Rainier Mesa in February 1984 resulted in an unexpected subsidence crater on the surface, causing injuries and one fatality. The nuclear device had been exploded at about 360 meters (1,184 feet) below the surface (DOE/NVO, 1984), and the persons injured were involved in post-shot activities only 26 meters (85 feet) from the point on the surface that was directly above the explosion. Surface cratering occurs above some underground nuclear tests. All known effects, such as fractures, have been very close to the site of the explosion. Ninety-five percent of the after-shocks at Pahute Mesa have been found to be within 14 kilometers (8.7 miles) of the explosion site (ERDA, 1977). The Yucca Mountain site is sufficiently distant from present or potential underground test locations that collapse or formation of fractures is highly unlikely.

In an analysis of the compatibility of a repository at the Yucca Mountain site and the weapons-testing program with respect to ground motion, Vortman (1982) summarized the following significant differences between ground motion from weapons tests and natural earthquakes: (1) the timing of weapons tests is known and controlled; (2) the seismic-source location for a

weapons test is known; (3) a conservative upper limit on the expected explosion energy is available; and (4) an experienced test organization controls the safety aspects of weapons tests. Standard operating practices should be able to ensure personnel safety and protect surface and underground facilities.

Using an empirical relationship developed on the basis of ground motion studies from past weapons tests, Vortman (1982) investigated potential conflicts with respect to induced ground motion between the underground weapons-testing program and a geologic repository at Yucca Mountain. His results show that if a repository was designed for a 0.75g ground acceleration, then it could be built as close as 6.3 kilometers (3.9 miles) to a 700-kiloton nuclear detonation. The closest location at the NTS with a potential for a 700-kiloton detonation is the Buckboard area, and it is 23 kilometers (14 miles) from the Yucca Mountain site, more than 3 times farther than the 6.3 kilometers (3.9 miles) calculated by Vortman (1982). Ground motion from aftershocks that follow large nuclear tests has also been considered and should not cause additional problems; as noted above, 95 percent of the stimulated earthquake activity is confined to within 14 kilometers (8.7 miles) of the detonation point. Aftershocks fall off to the background level within a period of several weeks, and the strongest aftershock is usually at least 2 magnitude units (on a logarithmic scale) less than the explosion (ERDA, 1977).

A repository at the Yucca Mountain site can be designed and constructed using available technology to withstand the maximum credible predicted ground motion, whether natural or induced (see discussion in Section 6.3.3.4.5). Using the empirical equation from Vortman (1980), the predicted mean peak vector ground acceleration at Yucca Mountain from underground nuclear explosions at the maximum allowable yields, based on offsite damage restrictions, is calculated to be 0.061g. Using a very conservative design criterion of three standard deviations, or 99 percent of all probable values, the mean peak vector ground acceleration for Yucca Mountain is calculated to be 0.32g. The yields used for this calculation are well above the 150-kiloton limit currently allowed by the Threshold Test Ban Treaty. The suspension of certain activities at the repository site can be planned as a standard operating procedure. These suspensions will be infrequent and of short duration; they will not have significant adverse effects on any phase of repository activities.

No detectable levels of radioactivity from the underground testing program were observed outside the NTS boundaries during four of the past five 1-year reporting periods for which data have been compiled (see Table 6-7). Current radiation-containment and safety measures are more stringent than in the past, and the possibility of substantial releases of radioactivity to the atmosphere in the future is considered very small (ERDA, 1977). Radioactivity attributable to the resuspension of dust particles in the air from contaminated areas at the NTS has never been detected off the site (ERDA, 1977).

Conclusion

All potential impacts from atomic energy defense activities occurring elsewhere at the NTS can be accommodated by careful facility design and

construction and through the compatible scheduling of repository operations and nuclear weapons testing activities. Consequently, atomic energy defense activities in proximity to the site are not expected to conflict irreconcilably with repository siting, construction, operation, closure, and decommissioning. Therefore, the evidence does not support a finding that the Yucca Mountain site is disqualified (level 1).

6.2.1.5.6 Evaluation and conclusion for the qualifying condition on the offsite installations and operations guideline

Evaluation

A repository at Yucca Mountain will be designed and constructed to withstand the ground motion predicted from nuclear-weapons testing at the Nevada Test Site (NTS) and from natural earthquakes. The design of earthquake-resistant structures will incorporate engineering experience and consider the maximum potential ground motion. There were no radionuclide releases from the NTS detected off the site during four of the past five 1-year monitoring periods. This information, combined with estimates of radionuclide releases from worst-case accident scenarios, provides confidence that radionuclide releases to an unrestricted area will not exceed allowable limits. Two or three nuclear tests per year may require temporary suspension of repository activities, usually not exceeding 12 hours. The portion of Nellis Air Force Range near Yucca Mountain is used only for military-aircraft overflights. These over-flights will increase noise in the area, and there is an extremely remote chance that an airplane might crash in the vicinity of the site; the probability of such a crash has been estimated at less than 2.0×10^{-10} per year (Jackson et al., 1984).

Releases during normal repository operation are discussed in Section 6.4.1. The estimated annual dose equivalent due to normal releases would be approximately 2 percent of background. The estimated worst-case accidental radionuclide release from the repository results from an aircraft impact accident, which causes a maximum individual total-body dose of 5.5×10^{-2} rem or a 50-year dose commitment of 6.8×10^{-2} rem (Jackson et al., 1984). This accident has a very low risk (less than 2.2×10^{-8} man-rem per year) because the probability of occurrence of this accident is extremely small, less than 2.0×10^{-10} per year. If the dose from this very unlikely scenario is considered together with the maximum dose calculated for releases detected off the site from 1974 to 1983 (11 microrem in 1980), the maximum possible total-body dose would increase by only 0.02 percent, not enough to cause regulatory limits to be exceeded.

Conclusion

Nearby industrial and military installations and operations will not significantly affect a potential repository at Yucca Mountain during siting, construction, operation, closure, or decommissioning. Possible short-term interruption of activities at a repository due to weapons tests is not considered a significant effect. Any potential emissions during construction, operation, closure, and decommissioning in combination with those that might occur from activities at the NTS will not lead to radionuclide releases to an unrestricted area greater than allowable under present regulations. This is true for both normal repository operation and for worst-case accident

scenarios. Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition for offsite installations and operations (level 3).

6.2.1.6 Environmental quality (10 CFR 960.5-2-5)

6.2.1.6.1 Introduction

The qualifying condition for this guideline is as follows:

The site shall be located such that (1) the quality of the environment in the affected area during this and future generations will be adequately protected during repository siting, construction, operation, closure, and decommissioning, and projected environmental impacts in the affected area can be mitigated to an acceptable degree, taking into account programmatic, technical, social, economic, and environmental factors; and (2) the requirements specified in Section 960.5-1(a)(2), can be met.

The preclosure environmental-quality technical guideline is concerned with ensuring that the quality of the natural and human environment will be protected throughout all stages of the geologic-repository program and that the projected impacts can be mitigated to an acceptable degree.

The guideline contains two favorable conditions, six potentially adverse conditions, three disqualifying conditions, and one qualifying condition. The evaluations presented below are summarized in Table 6-8.

6.2.1.6.2 Data relevant to the evaluation

The following information was used to evaluate the Yucca Mountain site against the guideline on environmental quality: (1) published reports describing the archaeology, biology, hydrology, meteorology, and radiology of the Yucca Mountain area (see Chapter 3); (2) a preliminary investigation of the regulatory requirements that could apply to a repository at Yucca Mountain (see favorable condition 1); (3) a variety of land-status maps published by the State of Nevada and by the Bureau of Land Management (see potentially adverse condition 2); and (4) the results of analyses in chapters 4 and 5 that describe the expected near- and long-term environmental consequences of repository siting, construction, operation, closure, and decommissioning at Yucca Mountain.

Table 6-9 presents a preliminary list of the Federal regulatory requirements that may apply to repository siting, construction, operation, closure, and decommissioning at Yucca Mountain.

Table 6-10 lists State environmental regulatory requirements. There are no applicable local environmental requirements. The U.S. Department of Energy (DOE) intends to comply with all State and local environmental requirements not inconsistent with its responsibilities under the Nuclear

Table 6-8. Summary of analyses for Section 6.2.1.6; environmental quality (10 CFR 960.5-2-5)

Condition	Department of Energy (DOE) finding
<p>FAVORABLE CONDITIONS</p>	
(1) Projected ability to meet, within time constraints, all Federal, State, and local procedural and substantive environmental requirements applicable to the site and the activities proposed to take place thereon.	The evidence indicates that this favorable condition is present at Yucca Mountain: no problems are expected in siting, constructing, operating, closing, and decommissioning the repository in compliance with applicable environmental requirements.
(2) Potential significant adverse environmental impacts to present and future generations can be mitigated to an insignificant level through the application of reasonable measures, taking into account technical, social, economic, and environmental factors.	The evidence indicates that this favorable condition is present at Yucca Mountain: potential impacts are not expected to be significant; mitigation measures can be taken to further reduce those adverse impacts that may result from siting, constructing, operating, closing, and decommissioning a repository at Yucca Mountain.
<p>POTENTIALLY ADVERSE CONDITIONS</p>	
(1) Projected major conflict with applicable Federal, State, or local environmental requirements.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: no major conflicts with existing requirements have been identified.
(2) Projected significant adverse environmental impacts that cannot be avoided or mitigated.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: potential impacts are not expected to be significant; mitigation measures can be taken to further reduce those adverse impacts that may result from siting, constructing, operating, closing, and decommissioning a repository at Yucca Mountain.

Table 6-8. Summary of analyses for Section 6.2.1.6; environmental quality (10 CFR 960.5-2-5) (continued)

Condition	Department of Energy (DOE) finding
(3) Proximity to, or projected significant adverse environmental impacts of the repository or its support facilities on a component of the National Park System, the National Wildlife Refuge System, the National Wild and Scenic Rivers System, the National Wilderness Preservation System, or National Forest Land.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: the proposed rail line within a few miles of the Desert National Wildlife Range is not expected to have an adverse effect on animals or people on the range; there are no other federally protected lands that could be significantly affected.
(4) Proximity to, and projected significant adverse environmental impacts of the repository or its support facilities on a significant State or regional protected resource area, such as a State park, a wildlife area, or a historical area.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: a proposed rail line may pass about 2 kilometers (1 mile) north of a State park, but noise is not expected to exceed EPA limits; no other resource area is affected.
(5) Proximity to, and projected significant adverse environmental impacts of the repository and its support facilities on a significant Native American resource, such as a major Indian religious site, or other sites of unique cultural interest.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: few archaeological or historical sites may be affected during construction, but sites that could be disturbed will be excavated, and artifacts will be collected and (or) catalogued.

Table 6-8. Summary of analyses for Section 6.2.1.6; environmental quality (10 CFR 960.5-2-5) (continued)

Condition	Department of Energy (DOE) finding
(6) Presence of critical habitats for threatened or endangered species that may be compromised by the repository or its support facilities.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain because no listed threatened or endangered species occur in the study area. The repository and support facilities are not expected to have significant adverse impact on the two species under review as threatened or endangered or on the State-protected species. The nearest endangered species are pupfish that occur in Ash Meadows 40 kilometers (25 miles) south of the site: their habitat is protected by land-use restrictions, and is located in a different groundwater basin.
<p style="text-align: center;">QUALIFYING CONDITION</p> <p>The site shall be located such that (1) the quality of the environment in the affected area during this and future generations will be adequately protected during repository siting, construction, operation, closure, and decommissioning, and projected environmental impacts in the affected area can be mitigated to an acceptable degree, taking into account programmatic, technical, social, economic, and environmental factors; and (2) the requirements specified in Section 960.5-1(a)(2) can be met.</p>	
<p>Existing information does not support a finding that the site is not likely to meet the qualifying condition (level 3): no projected significant impacts have been identified, and there is no reason to expect that applicable environmental requirements cannot be met by designs and procedures during siting, constructing, operating, closing, and decommissioning of a repository at Yucca Mountain. The public and the environment are expected to be adequately protected from the hazards posed by the disposal of radioactive waste.</p>	

Table 6-9. Preliminary summary of Federal environmental regulatory requirements that may apply to a repository at Yucca Mountain (See footnotes at the end of the table)

Authority	Project Feature	Substantive Requirements
REQUIREMENTS RELATED TO LAND		
National Environmental Policy Act of 1969 (NEPA). Compliance with regulations.	Major Federal actions significantly affecting the quality of the human environment.	This Act requires Federal agencies to assess the environmental impacts of major Federal actions to prevent or eliminate damage to the environment.
Federal Land Policy and Management Act, and summary report on 43 USC ^a 1701-1782. Right-of-Way Grant (BLM ^b or USFS ^c).	Occupation, use, or traversing of land for roads, railroads, power, construction camps, storage yards, etc., will affect BLM land.	A description of the land environmental effects; BLM evaluates effects and sends written authorization.
Fish & Wildlife Coordination Act, 16 USC 661 <u>et seq.</u> , Section 4(f); Department of Transportation Act of 1966, 80 Stat. 931, P.L. 89-870; National Wildlife Refuge System Administration Act, P.L. 89-669, (USFWS ^d , DOI ^e). Right-of-Way Consultation.	Occupation, use, or traversing of land for power and railroads over national wildlife refuges. Effects to the Desert National Wildlife Range, are not expected. The Secretary of Transportation must approve a transportation project if publicly owned land containing a public park, recreation area, or wildlife area are affected.	A description of the species, the habitat, and how the proposed action may affect the species; USFWS or DOT ^f evaluates information; needed action, and instructs applicant.
Federal Land Policy and Management Act, 43 USC 155-158, (BLM, USFS). Withdrawal Land Order.	Obtaining jurisdiction over, use of, or occupation of public land for facilities and structures will affect BLM land.	An environmental assessment may be required.

Table 6-9. Preliminary summary of Federal environmental regulatory requirements that may apply to a repository at Yucca Mountain (See footnotes at the end of the table) (continued)

Authority	Project Feature	Substantive Requirements
Federal Land Policy and Management Act, sections 103(f), 302(b), 501(a)(7), 504(a), and 507(a) (BLM, USFS). Temporary Use Permit.	Occupation, use, or traversing of public land to study, monitor, or perform other investigations will affect BLM land.	A description of the land and a summary report on environmental effects; BLM returns an approved permit application form.
Organic Act of the National Park Service, 16 USC Section 1; National Park System Mining Regulation Act, 16 USC Section 1901-1912 (36 CFR ⁸ Part 9).	Occupation, use, or traversing of National Park land. To preserve National Parks and to leave them unimpaired for future generations with special emphasis on halting or regulating mining so as to prevent or minimize damage to the environmental resources.	A description of the land and a summary report on the environmental impact; this Act is not applicable because the restricted area or repository support facilities will not lie within a National Park.
Department of Transportation Acts, 49 USC Section 303, 23 USC Section 138.	Occupation, use, or traversing of public land for transportation corridors. To preserve the natural beauty of the countryside, public parks, recreation lands, wildlife and waterfowl refuges, and historic sites.	A description of the land and a summary report on the environmental impacts; although the Acts do not impose any requirements directly on the DOE ^h , the DOE will consult with the Department of Transportation to determine the applicability.
Coastal Barriers Resources Act, 16 USC 3501-3510.	Prohibits new Federal expenditures for construction of projects within the Coastal Barrier Resources System (CBRS), undeveloped coastal land along the Atlantic and Gulf Coasts, and adjacent wetlands and inlets.	DOE determines if candidate site or related activities are within CBRS; if so, site or activities must be abandoned. DOE confirms with U.S. Fish and Wildlife Service that no project activities are located in a coastal barrier.

Table 6-9. Preliminary summary of Federal environmental regulatory requirements that may apply to a repository at Yucca Mountain (See footnotes at the end of the table) (continued)

Authority	Project Feature	Substantive Requirements
REQUIREMENTS RELATED TO LAND (continued)		
Coastal Zone Management Act of 1972, 16 USC 1451-1464 (15 CFR 930).	Coastal Zone Management Act ensures that any Federal project in the coastal zone, is consistent with approved state management programs.	DOE determines if project activities are in, or could affect, the coastal zone of a state. If DOE determines that a coastal zone is affected, or that ocean dumping is proposed, additional requirements apply.
Marine Protection, Research, and Sanctuaries Act, 33 USC 1401-1444 (10 CFR 220-228).	Marine Protection, Research, and Sanctuaries Act regulates the dumping of all types of materials into ocean waters.	If DOE determines that ocean dumping is proposed, additional requirements apply.
Wild and Scenic Rivers Act, 16 USC 1271-1287.	Act prohibits construction on or directly affecting any river that is designated a component of the National Wild and Scenic River (NWSR) system, or on any river designated for addition to the system, that would adversely affect the values of NWSR systems.	DOE determines if any rivers in the vicinity of the candidate repository site are designated as a component of the NWSR system, or a potential addition to the system. If DOE finds an NWSR in site vicinity, it must prepare an impact evaluation. If impacts are direct and adverse, DOE must advise the Secretary of the Department of Interior and Congress.
Wilderness Act, 16 USC 1131-1136. (Federal Land Policy and Wilderness Management Act, 43 USC 1982).	Act establishes a National Wilderness Preservation System for public recreational, scenic, scientific, educational, conservation, and historical use.	Roads, structures, installations, etc., are prohibited in designated Areas or Wilderness Study Areas (WSAs).

Table 6-9. Preliminary summary of Federal environmental regulatory requirements that may apply to a repository at Yucca Mountain (See footnotes at the end of the table) (continued)

Authority	Project Feature	Substantive Requirements
REQUIREMENTS RELATED TO LAND (continued)		
Taylor Grazing Act 43 USC 315-316 (43 CFR 4100).	Act creates, protects, and regulates Federal grazing districts to provide for the orderly use and development of rangeland.	If repository site or access is located on a DOI Bureau of Land Management (BLM) designated grazing district, DOE must apply for a right-of-way, or withdrawal of grazing district land from BLM.
National Forest Organic Legislation, 16 USC 475; Multiple-Use-Sustained-Yield Act, 16 USC 528-531; Forest and Rangeland Renewable Resources Planning and Research Acts, Management Act, and Renewable Resource Extension Act, 16 USC 1600-1676 (36 CFR Part 261).	Acts protect and improve National Forests which are established for outdoor recreation, range, timber, watershed, and fish and wildlife purposes.	DOE must obtain Congressional approval for withdrawal of National Forest land for DOE use as a repository site. Access roads on National Forest land must be built in accordance with requirements defined by the DOA ¹ . Permanent roads must be approved as part of National Forest Transportation System.
Farmland Protection Policy Act, 7 USC 4201-4209 (7 CFR 658).	Act seeks to minimize the extent to which Federal programs contribute to the unnecessary and irreversible conversion of farmland to nonagriculture uses.	DOE must complete Soil Conservation Service (SCS) Form AD 1006, and submit to SCS. If SCS determines that prime farmland exists on site, DOE must complete a site assessment. DOE must also consider alternative/mitigating measures to protect the prime farmland, and assure to extent practicable, project compatibility with State and local programs and policies.

Table 6-9. Preliminary summary of Federal environmental regulatory requirements that may apply to a repository at Yucca Mountain (See footnotes at the end of the table) (continued)

Authority	Project Feature	Substantive Requirements
REQUIREMENTS RELATED TO LAND (continued)		
Floodplains/Wetlands Executive Orders, E.O. 11988 and 11990 (10 CFR 1022).	Executive Orders require Federal agencies to implement regulations that will protect wetlands, and minimize adverse effects from development in floodplains.	If wetlands or floodplains occur at the site or support facilities, DOE must publish notice in Federal Register, notify Federal, State, and local agencies of proposed action, prepare an assessment of proposed action, and publish a statement of findings. Construction in a flood plain must be in accordance with Federal Insurance Administration regulations.
REQUIREMENTS RELATED TO AIR OR NOISE		
Clean Air Act, 42 USC 7401, <u>et seq.</u> (Regional EPA Office). Preconstruction Permit under Prevention of Significant Deterioration (PSD) or nonattainment regulations; EPA ^J review only for states with delegated authority.	Any major stationary source including concrete or asphalt batch plants, fossil-fuel-fired equipment diesel generator, storage of volatile organic compounds, etc.	An emission inventory, meteorology data, dispersion modeling, and an evaluation of NAAQS ^K and PSD standards; EPA returns signed application forms.
Clean Air Act, 42 USC 7410(a)(2)(D), 110(a)(4) (State Air Quality Office). New Source Review (NSR) provisions of the Clean Air Act authorize States to regulate sources not subject to PSD through permit programs.	Small sources and sources not subject to PSD or nonattainment review, but subject to new source operating standards and emission limitations.	A list of emissions and emission sources; EPA uses NSR to ensure compliance with New Source Review emission standards; EPA issues NSR approval; activity must be included in approved State Implementation Plan (SIP).

Table 6-9. Preliminary summary of Federal environmental regulatory requirements that may apply to a repository at Yucca Mountain (See footnotes at the end of the table) (continued)

Authority	Project Feature	Substantive Requirements
REQUIREMENTS RELATED TO AIR OR NOISE (continued)		
Noise Control Act of 1972, 42 USC 4901-4918.	Federal agencies are to carry out their programs in a manner that promotes an environment free of noise that could jeopardize health or welfare.	DOE is required to comply with Federal, State, interstate, and local requirements for the control and abatement of environmental noise.
REQUIREMENTS RELATED TO WATER		
Federal Land Policy and Management Act, 43 USC 1767 (BLM). Right-of-Way Grants.	Well sites on BLM land.	Well specifications, location, use, and brief description of environmental effects; BLM returns a signed right-of-way form.
Clean Water Act 33 USC 1251, et seq. (Regional EPA Office). National Pollutant Discharge Elimination System Permit.	Discharge of pollutants into project surface lagoons that could subsequently lead to contamination of surface or ground waters.	Discharge quantity, water quality data, and information on receiving waters; EPA returns a signed application form.
Clean Water Act, Sec. 404, 33 USC 1344; Executive Orders 11988 and 11990 (District U.S. Coast Guard). 404 Permit/ Consultation.	Discharge of dredged material for purposes of building impoundments, causeways, roadfills, dams, or dikes in navigable waters, including wetlands; depends on the official classification of Fortymile Wash.	Description of activity and environmental impact report; ACOE returns a signed application form.
Clean Water Act, Sec. 311(j)(1)(c); 40 CFR 112 (Regional EPA Office). Approval of Spill Prevention Control and Counter-measure (SPCC) Plan.	Storage and transport of hydrocarbons near navigable waters; spill prevention depending on the classification of Fortymile Wash.	Location and specifications of tanks and berms to confine spills; EPA approves the SPCC Plan in writing.

Table 6-9. Preliminary summary of Federal environmental regulatory requirements that may apply to a repository at Yucca Mountain (See footnotes at the end of the table) (continued)

Authority	Project Feature	Substantive Requirements
REQUIREMENTS RELATED TO WATER (continued)		
Rivers and Harbors Act, 33 USC 401-413 (33 CFR 323).	Act prevents any alteration or modification of the course, location, conditions, or capacity of any channel of any navigable water of the U.S. without a permit.	DOE must obtain a permit from ACOE if fill material is put into navigable water.
General Bridge Act of 1946, 33 USC 401 (33 CFR 114-115).	Act requires permit or amendment from U.S. Coast Guard for construction or modification of bridges over any navigable waterways.	DOE must apply for permit if any bridge over navigable waterways will be built or modified as a result of repository activities at the site.
Safe Drinking Water Act, 42 USC 300f-300g-10 (40 CFR 122 and 146).	The purpose of the Act is to prevent pollution of underground sources of drinking water, to protect sole source aquifers and to require compliance with Federal, State, and local public drinking water regulations.	DOE must obtain an Underground Injection Control Permit or use a licensed underground injection well facility, if underground injection is chosen as method of disposal for brine.
REQUIREMENTS RELATED TO SOLID AND HAZARDOUS WASTE		
Hazardous Materials Transportation Act, 49 USC 1801, <u>et seq.</u> Registration	Packing, labeling, handling, documenting, and transporting hazardous materials on public roads, railways, etc. across state lines; hazardous materials include flammable liquids, combustible liquids, explosives, etc.	Documentation of materials to be transported; DOT returns a signed registration form.

Table 6-9. Preliminary summary of Federal environmental regulatory requirements that may apply to a repository at Yucca Mountain (See footnotes at the end of the table) (continued)

Authority	Project Feature	Substantive Requirements
REQUIREMENTS RELATED TO SOLID AND HAZARDOUS WASTE (continued)		
Resource Conservation and Recovery Act, USC 6901, <u>et seq.</u> (Regional EPA Office). Hazardous Waste Identification Number.	Generation and transport of hazardous wastes in quantities exceeding 1,000 kg/month or acute hazardous wastes exceeding 1 kg/month.	Quantity and type of waste and a description of disposal site before, during, and after disposal; EPA returns a signed application form.
Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), 42 USC Sections 9601-9657.	Generation and transport of hazardous wastes. The Act imposes notification requirements and liability for unpermitted releases of hazardous substances, and to establish a fund for remedial use in case of release of hazardous substances.	Notification and clean up of accidental spills in accordance with CERCLA requirements.
Resource Conservation and Recovery Act, USC 6901, <u>et seq.</u> (Regional EPA Office). Hazardous Waste TSD Permit (necessary for any state without an EPA-approved hazardous-waste-management plan).	Construction and operation of any facility used for the treatment, storage, and disposal (TSD) of hazardous wastes including possibly the rock-storage pile.	Quantity and type of waste and a description of disposal site before, during, and after disposal; EPA returns a signed application form.
REQUIREMENTS RELATED TO CULTURAL RESOURCES AND NATIVE AMERICANS		
American Indian Religious Freedom Act, 42 USC 1996 <u>et seq.</u> Consultation with Native American religious leaders, BIA ^m , DOI.	Impact of construction on American religious practices and sites.	Location of project activities and sites; DOI returns written authorization to proceed with project.

Table 6-9. Preliminary summary of Federal environmental regulatory requirements that may apply to a repository at Yucca Mountain (See footnotes at the end of the table) (continued)

Authority	Project Feature	Substantive Requirements
REQUIREMENTS RELATED TO CULTURAL RESOURCES AND NATIVE AMERICANS (continued)		
National Historic Preservation Act, 16 USC 470 <u>et seq.</u> , Executive Order 11593; 35 CFR 800. (Advisory Council on National Historic Preservation; State Historic Preservation Office).	Impact of construction on cultural resources.	As above, DOI action required.
Determination of No Adverse Effect; Programmatic Memorandum of Agreement; Avoidance and Mitigation for land withdrawal where excavations or removal of archaeological resources are anticipated.		
Archaeological Resources Protection Act of 1979, 16 USC 470 <u>aa et seq.</u> (BLM, DOI, DOA). Permit to excavate, remove, or alter archaeological resources.	Impact of construction on cultural resources.	As above, and a detailed excavation preservation plan; DOI must approve the plan.
American Antiquities Act, 16 USC 433.	Act protects historic and prehistoric ruins, monuments, and objects of antiquity located on lands owned or controlled by the Federal Government.	If historic or prehistoric ruins or objects of antiquity are found, DOE must determine if project will adversely affect sources. Secretary of the DOI will have to grant permission to proceed before activities can be undertaken that may result in appropriation, excavation, injury, or destruction to any historic ruin or antiquity.

Table 6-9. Preliminary summary of Federal environmental regulatory requirements that may apply to a repository at Yucca Mountain (See footnotes at the end of the table) (continued)

Authority	Project Feature	Substantive Requirements
REQUIREMENTS RELATED TO CULTURAL RESOURCES AND NATIVE AMERICANS (continued)		
Reservoir Salvage Act of 1960, 16 USC Section 469-469c (at 469 a-1) (DOI). Survey for recovery and preservation of archaeological resources discovered in the course of siting a Federal project.	Impacts of construction on cultural resources.	As above, DOI action required.
National Trails System Act, 16 USC, Section 1241 et seq. (NPS ⁿ , DOI). Cooperative Agreement for construction and operation on historic trails.	Impacts of construction on historic trails.	As above, DOI action required.
Historic Sites, Buildings and Antiquities Act, 16 USC 461-469; Preservation of Historical Archaeological Data Threatened by Dam Construction or Alteration; Historic Preservation Act of 1966 as Amended, 16 USC 470-470w-6 (36 CFR Part 800); (E.O. 11593).	Act protects properties of historical architectural significance at National, State, and local levels from Federal actions affecting properties included in or eligible for inclusion in the National Register of Historic Places.	DOE must request information from State Historic Preservation Officer (SHPO) and study existing literature to determine whether potential structures or objects that are listed in the National Register or are eligible for inclusion in the National Register will be affected. If potential repository site contains historic resource that is eligible for inclusion in the National Register, DOE must determine the effect that repository construction may have on the resource.

Table 6-9. Preliminary summary of Federal environmental regulatory requirements that may apply to a repository at Yucca Mountain (See footnotes at the end of the table) (continued)

Authority	Project Feature	Substantive Requirements
REQUIREMENTS RELATED TO CULTURAL RESOURCES AND NATIVE AMERICANS (continued)		
		If effect would be adverse, DOE must prepare a plan of mitigation and consult with the Advisory Council on Historic Preservation.
REQUIREMENTS RELATED TO CONSTRUCTION MATERIALS		
Materials Act 1947, 30 USC 601-604 (43 CFR 3600 <u>et seq.</u>) (BLM, DOI). Free Use Permit.	Acquisition (from BLM lands) and use of common varieties of sand, stone, gravel, etc. for a public project.	A description of the excavation site before, during, and after activities; a brief mining plan and an environmental impact summary; BLM formally approves the plans.
REQUIREMENTS RELATED TO BIOLOGICAL ASPECTS		
Endangered Species Act 16 USC 1531 <u>et seq.</u> , Federal Land Management Policy Act (USFWS, DOI). Biological opinion on threatened and endangered species.	Construction and operation activities affecting flora and fauna.	A project description, a biological survey, and a report of findings; USFWS approves the information in writing.
Sikes Act, P.L. 93-452 (16 USC 679 <u>et seq.</u> , (BLM). Consultation.	Construction activities within BLM and State Wildlife Agency Wildlife Habitat areas.	As above, USFWS action required.

Table 6-9. Preliminary summary of Federal environmental regulatory requirements that may apply to a repository at Yucca Mountain (See footnotes at the end of the table) (continued)

Authority	Project Feature	Substantive Requirements
REQUIREMENTS RELATED TO BIOLOGICAL ASPECTS (continued)		
Migratory Bird Treaty Act, 16 USC 703-710 (50 CFR 10.13)	Act prohibits killing, capturing, transporting, etc., protected migratory birds, their nests, and eggs.	Project activities must avoid harm (including indirect effects) to migratory birds, their nests, and eggs.
Bald and Golden Eagle Protection Act, 16 USC 668-668d.	Act prohibits possessing, killing, transporting, disturbing, etc., bald and golden eagles, their nests, or eggs.	Project activities must avoid negative impacts to bald and golden eagles and their nests and eggs. Secretary of Interior may permit relocation of golden eagle nests if they interfere with resource development or recovery plans.
Wild Free-Roaming Horses and Burros Act, 16 USC 1331-1340 (43 CFR 4700).	Act protects all unbranded and unclaimed horses and burros on public lands of the United States.	Project activities must avoid harm (including indirect effects) to wild, free-roaming horses and burros on public lands.
National Wildlife Refuge System Administration Act of 1966, 16 USC Sections 668dd-668ee (50 CFR Parts 25, 27, 28, and 29).	Project activities that would conflict with the protection and conservation of national wildlife refuges.	A description of the project, the land to be disturbed and a summary report on the environmental impacts.

Table 6-9. Preliminary summary of Federal environmental regulatory requirements that may apply to a repository at Yucca Mountain (See footnotes at the end of the table) (continued)

Authority	Project Feature	Substantive Requirements
REQUIREMENTS OR PERMITS RELATED TO AIR SPACE		
Federal Aviation Act, 49 USC 1347 <u>et seq.</u> , (FAA) ^o . Airspace Permit.	Buildings, towers, or other structures exceed- ing 200 ft in height.	A description of activi- ties showing structures over 200 ft; FAA approves a formal application form.

- ^aUSC = United States Code.
^bBLM = Bureau of Land Management.
^cUSFS = U.S. Forest Service.
^dUSFWS = U.S. Fish and Wildlife Service.
^eDOI = U.S. Department of Interior.
^fDOT = U.S. Department of Transportation.
^gCFR = Code of Federal Regulations.
^hDOE = U.S. Department of Energy.
ⁱDOA = U.S. Department of Agriculture.
^jEPA = U.S. Environmental Protection Agency.
^kNAAQS = National Ambient Air Quality Standard.
^lACOE = Army Corps of Engineers.
^mBIA = Bureau of Indian Affairs.
ⁿNPS = National Park Service.
^oFAA = Federal Aviation Authority.

Table 6-10. Preliminary summary of State environmental regulatory requirements that may apply to a repository at Yucca Mountain (See footnotes at end of table)

Authority	Project feature	Substantive requirements
REQUIREMENTS RELATED TO WATER		
NRS ^a Chapter 445.131 through 445.354; National Pollutant Discharge Elimination System Permit NDEP ^b ; EPA ^c Region IX San Francisco.	Any activity that may result in a discharge of pollutants into State waters (either surface or underground).	Discharge quantity and water quality data, data on receiving waters and impacts; EPA approves application form.
NRS Chapter 533 and 534; Permit to appropriate the Public Waters; NDWR ^d .	Location of point of diversion and place of use, use for water, annual consumption of water.	Intake (well) specifications, location, and use; Nevada approves application form.
REQUIREMENTS RELATED TO SAFETY		
NRS 618; Construction and Operating Permit for New Elevators, Dumbwaiters and Moving Walks; NDOSH ^e .	Assembly, installation, testing, and inspection of elevators, dumbwaiters, and moving walks.	Description of facility; Nevada approves Health and Safety Plan.
NRS 618; Boiler or Pressure Vessel Operating Permit; NDOSH.	Operation of a boiler or pressure vessel.	Description of facility; Nevada approves the permit application.
REQUIREMENTS RELATED TO LAND USE		
NRS 278, 439.200, 444, 445, and 446; Permit to Construct a Campsite; NDH ^f (Bureau of Consumer Health Protection Services).	Construction of labor camps, public bathing places, mobile home parks, camp kitchen & dining room, drinking water supply, recreational vehicle park, sewage system, or subdivision.	Specifications on all facilities; Nevada approves various application forms.

Table 6-10. Preliminary summary of State environmental regulatory requirements that may apply to a repository at Yucca Mountain (See footnotes at end of table) (continued)

Authority	Project feature	Substantive requirements
REQUIREMENTS RELATED TO LAND USE (continued)		
NRS Chapter 512.160; Opening and Closing Mines; NSIM ^g .	Opening and closing mining operations.	A notification form to be filed with the Inspector of Mines; Nevada approves form.
NRS Chapter 535; Permit to Construct Tailing Dam; if fresh-water storage, a Storage Permit is also required; NDWR.	Any tailing dam that is higher than 10 feet or or will impound more than 10 acre-feet.	Specifications on the dam and water relocation and drainage system; Nevada approves plans.
NRS Chapter 444.440 through 444.620; Solid Waste Management System; NDEP.	Any place where solid waste is dumped, abandoned, accepted, or disposed of by incineration, land filling, composting, or any other method. (This does not prevent a mining operation from dumping waste from its operation on its own land.)	Description of activities; Nevada approves plans.
NRS 322; Lease-Easement; NDSL ^h .	The construction of bridges, pipelines, and water or sewer lines.	Facility specifications and description of construction activities; Nevada approves plans.
NRS 459.010 through 459.290; Radioactive Materials License; NDH (Bureau of Consumer Health Protection Services).	The use, storage, disposal, and extraction of certain nonexempt radioactive materials.	Description of materials, uses, and handling methods and procedures; Nevada approves license application.
NRS 444.700 through 444.778; Hazardous Waste Management; NDEP.	Storage, generation, transportation, treatment and disposal of hazardous waste.	See Federal Resource Conservation and Recovery Act.

Table 6-10. Preliminary summary of State environmental regulatory requirements that may apply to a repository at Yucca Mountain (See footnotes at end of table) (continued)

Authority	Project feature	Substantive requirements
REQUIREMENTS RELATED TO LAND USE (continued)		
Federal Regulations; Coordination; NDHPA ¹ .	Historic preservation.	See Federal Cultural Resources Section, Table 6-9.
NAC ^j 504.510 through 504.550; Special Permit--Modification of Habitat; NDW ^k .	Any action that will change or alter wild life habitat, including thermal pollution.	Description of proposed activity and environmental impacts; Nevada approves activity in writing.
REQUIREMENTS RELATED TO AIR QUALITY		
NRS Chapter 445.401 through 445.601; Air Quality--Permit to Construct (Registration Certificate); NDEP.	Any boiler over 4 million BTU, incinerators, mining operations, asphalt plants, cement plants, and other industrial processes.	Application form and support data including emissions, engineering equipment specifications, meteorology data, dispersion modeling, effects to environment compared with NAAQS ¹ and PSD ^m standards; Nevada approves application form.
NRS Chapter 445.401 through 445.601; Air Quality--Permit to Operate; NDEP.	Compliance with construction permit within 180 days of startup of facility.	As above.
NRS Chapter 445.401 through 445.601; Air Quality--Prevention of Significant Deterioration; NDEP.	Major stationary sources (28 categories) and any source that emits greater than 250 tons/yr of a major pollutant.	As above.

Table 6-10. Preliminary summary of State environmental regulatory requirements that may apply to a repository at Yucca Mountain (See footnotes at end of table) (continued)

Authority	Project feature	Substantive requirements
REQUIREMENTS RELATED TO AIR QUALITY (continued)		
NRS 445.401 through 445.601; Air Quality--Permit to Construct (Registration Certificate) or Permit to operate; NDEP.	Any surface disturbance of 8 hectares (20 acres) or more; clearing, leveling, excavating or for the deposit of any foreign material to fill or cover such land.	As above.

^aNRS = Nevada Revised Statutes.

^bNDEP = Nevada Division of Environmental Protection.

^cEPA = Environmental Protection Agency.

^dNDWR = Nevada Division of Water Resources.

^eNDOSH = Nevada Division of Occupational Safety and Health.

^fNDH = Nevada Department of Health.

^gNSIM = Nevada State Inspector of Mines.

^hNDSL = Nevada Division of State Lands.

ⁱNDHPA = Nevada Division of Historic Preservation and Archaeology.

^jNAC = Nevada Administrative Code.

^kNDW = Nevada Department of Wildlife.

^lNAAQS = National Ambient Air Quality Standard.

^mPSD = Prevention of Significant Deterioration.

Waste Policy Act of 1982 (NWPA, 1983). The DOE intends to consult with appropriate State and local officials concerning sites that are recommended to determine the scope of the above noted requirements and identify other regulations as appropriate.

Assumptions and data uncertainties

The assumptions and uncertainties in the data used to evaluate the environmental quality guideline result from having only preliminary design studies available for the exploratory shaft and repository at Yucca Mountain (see chapters 4 and 5). Because only preliminary information is available, the evaluation of environmental impacts must also be considered preliminary. Specific assumptions and uncertainties in the data used to evaluate this technical guideline are described in chapters 4 and 5.

Assessing the significance of environmental impacts also has inherent uncertainties because of uncertainties in the criteria and the validity of the assumptions used to evaluate the significance of the environmental impacts. In general, easily verifiable impacts, such as irreconcilable conflicts with the designated uses of federally protected lands, can be evaluated with a high degree of certainty because the significance of the impact is defined clearly. In contrast, the significance of the effects exerted by the siting, construction, and operation of a repository on ground water or biotic communities is generally less certain. In estimating the significance of such potential environmental impacts that cannot be defined precisely, it is necessary to rely on the judgment of environmental specialists. The uncertainties will be minimized through ongoing investigations, the results of which will be described in an environmental impact statement if Yucca Mountain is selected as a site for further study (site characterization).

6.2.1.6.3 Favorable conditions

(1) Projected ability to meet, within time constraints, all Federal, State, and local procedural and substantive environmental requirements applicable to the site and the activities proposed to take place thereon.

Evaluation

A preliminary list of Federal and State environmental requirements that currently exist and may apply to the siting, construction, operation, closure, and decommissioning of a repository at Yucca Mountain is given in tables 6-9 and 6-10 (there are no applicable local environmental requirements). In some instances, the cited authority may require the U.S. Department of Energy (DOE) to obtain several different types of permits; in other instances the authority may require the DOE to consult with or notify the appropriate agency. A preliminary evaluation of the listed environmental requirements with regard to the site information presented in Chapter 3 and the potential environmental impacts presented in chapters 4 and 5 has been conducted. In addition, the DOE intends to comply with all State and local environmental requirements not inconsistent with the DOE responsibilities under the Nuclear Waste Policy Act (the Act) of 1982 (NWPA, 1983) as a matter of policy.

Conclusion

On the basis of the site information presented in Chapter 3 and the currently proposed activities and associated potential impacts as presented in chapters 4 and 5 evaluated with respect to current Federal, State, and local environmental requirements, no reason has been identified that would suggest that such requirements cannot be met, within time constraints, during the siting, construction, operation, closure, and decommissioning of a repository at the Yucca Mountain site. It has been assumed in this evaluation that current requirements would be interpreted and applied consistently with historical interpretation and application to activities of a similar scope and impact and that future requirements would not be inconsistent with the DOE responsibilities under the Act. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(2) Potential significant adverse environmental impacts to present and future generations can be mitigated to an insignificant level through the application of reasonable measures, taking into account programmatic, technical, social, economic, and environmental factors.

Evaluation

The adverse environmental impacts associated with the siting, construction, operation, closure, and decommissioning of a repository at Yucca Mountain are described in chapters 4 and 5. The major impact associated with site-characterization activities would be the disturbance of approximately 285 hectares (705 acres) of wildlife habitat. Other impacts include increased emissions of hydrocarbons and particulates and increased noise levels. Table 4-6 provides a summary of the environmental effects associated with site characterization. The impacts related to the repository include (1) the destruction of approximately 680 hectares (1,680 acres) of desert habitat, (2) fugitive-dust emissions, (3) vehicle emissions, and (4) radiation releases during the excavation and operation of the repository, and possibly from accidents. Radionuclide releases to the ground water in excess of limits set by 40 CFR Part 191 (1985) are not expected during operation or for thousands of years after decommissioning (Section 6.4). The significance of impacts to the biota from repository construction and operation are described in the evaluation of potentially adverse condition 6.

Emissions of fugitive dust will result from surface preparation, excavation, and the manipulation of the excavated rock and soil during the construction, operation, closure (backfilling), and decommissioning of the repository. Dust emissions will also result from the disturbance of approximately 486 hectares (1,200 acres) during the construction of a railroad to the repository, and from the disturbance of 79 hectares (195 acres) during the construction of an access road from U.S. Highway 95 north to the site. Carbon monoxide, hydrocarbons, and oxides of sulfur and nitrogen will be released from construction equipment and from private vehicles that transport workers to and from the site.

During repository construction, the emission rate and predicted impacts for particulates, carbon monoxide, hydrocarbons, and oxides of sulfur and nitrogen are not expected to exceed the air-quality limits of 40 CFR Part 50

(1983) at the boundary of the controlled area. Section 5.2.5 describes the models used to estimate the pollutants expected from repository construction, assuming no dust-suppression measures are taken. These models predict total suspended particulates of 130 micrograms per cubic meter for a ridge location and 132 micrograms per cubic meter for a valley location (Table 5-14). These concentrations are below the fugitive-dust standards in 40 CFR Part 50 (1983), which specify that a maximum allowable 24-hour concentration of 260 micrograms per cubic meter should not be exceeded more than once per year (Table 5-10). Section 5.2.5 provides a more complete discussion of air-quality regulations and estimated impacts. If the project is subject to Prevention of Significant Deterioration provisions of the Clean Air Act Amendments of 1977, the predicted pollutant concentrations would violate none of the applicable standards.

The release of naturally occurring radon and decay products from the volcanic rocks of Yucca Mountain will increase during repository excavation and during the manipulation of the excavated soil and rock (Table 5-22). Using estimates of natural radiation in granite (DOE, 1980a), an estimate of the release of natural radioactivity from the volcanic rocks of the Yucca Mountain site during construction can be calculated. Construction of a repository would result in an annual effective whole-body dose for a member of the general population of less than 0.05 millirem. Natural background radiation from all sources contributes an individual whole-body equivalent dose of 0.09 rem per year (Jackson et al., 1984). Routine releases from radon in the surface spoils piles during backfilling are expected to be negligible. The above estimates indicate that the environmental impact from radiological releases during excavation of the repository is not significant. See Section 6.4.1 for discussions of expected releases during normal repository operation, which are expected to represent less than 2 percent of natural background radiation.

Conclusion

No potential significant adverse environmental impacts to present or future generations have been identified from the siting, construction, operation, closure, and decommissioning of a repository at Yucca Mountain. Consequently, additional mitigation over that currently proposed is not required. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

6.2.1.6.4 Potentially adverse conditions

- (1) Projected major conflict with applicable Federal, State, or local environmental requirements.

Evaluation

The U.S. Department of Energy (DOE) will be required to obtain all applicable permits. Lists of the environmental regulations that may apply to siting, construction, operation, closure, or decommissioning of a repository at Yucca Mountain are given in tables 6-9 and 6-10. No major conflict with applicable Federal, State, or local environmental requirements is expected.

Conclusion

It is expected that all applicable Federal, State, and local environmental requirements will be satisfied. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(2) Projected significant adverse environmental impacts that cannot be avoided or mitigated.

Evaluation

The basis for concluding that the environmental impacts that would stem from siting, constructing, operating, closing, or decommissioning a repository at Yucca Mountain can be mitigated or avoided is given in the evaluation sections of favorable condition 2, potentially adverse condition 6, and in chapters 4 and 5.

Conclusion

The adverse environmental impacts expected from the siting, construction, operation, closure, and decommissioning of a repository can be mitigated to an acceptable degree or avoided. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(3) Proximity to, or projected significant adverse environmental impacts of the repository or its support facilities on, a component of the National Park System, the National Wildlife Refuge System, the National Wild and Scenic Rivers System, the National Wilderness Preservation System, or National Forest Land.

Evaluation

As discussed in Section 6.2.1.3, the surface and underground facilities at Yucca Mountain would be located entirely on Federal lands currently administered by the DOE and the U.S. Department of the Air Force (DAF) as well as public-domain lands under the jurisdiction of the Bureau of Land Management (BLM). As noted in the relevant data of Section 6.2.1.3, the proposed facilities would be located on Federal lands that are not currently restricted by environmental land-use considerations.

If a repository is located at Yucca Mountain, the proposed rail line would be constructed from Yucca Mountain to a point a few miles northeast of Las Vegas (see map of proposed rail routing, Chapter 5, Figure 5-2) and a paved access road would be built from U.S. Highway 95 approximately 25 kilometers (16 miles) northward to the site. At some points, the rail line may be within the vicinity of the southern boundary of the Desert National Wildlife Range (Lutsey and Nichols, 1972). Large parts of the wildlife range are administratively endorsed as suitable for inclusion in the National Wilderness Preservation System (BLM, 1983). The effects on the Desert National Wildlife Range due to the construction and operation of the rail line are expected to be minor because the rail line is not expected to traverse lands within the wildlife range. The proposed access route from

U.S. Highway 95 to the site would be entirely on federally controlled land with no conflicting uses.

The boundary of Death Valley National Monument lies approximately 30 to 40 kilometers (20 to 25 miles) west and southwest of the Yucca Mountain site (Lutsey and Nichols, 1972). The environmental effects of siting, constructing, and operating a repository at Yucca Mountain include increased use of the monument by the construction workers and the employees of the repository. This could produce some effect on the facilities and scenic attributes of the monument, but the significance of these impacts is expected to be minor.

The northern part of the controlled area surrounding the repository site would be approximately 8 kilometers (5 miles) south of the Timber Mountain Caldera National Natural Landmark. This federally designated landmark would not be disturbed during the construction and operation of the repository. Furthermore, the landmark is located within the Nellis Air Force Range and the Nevada Test Site, and access to it is restricted.

Recently, the U.S. Fish and Wildlife Service (USFWS) purchased 5,121 hectares (12,654 acres) of private land in the Ash Meadows area from the Nature Conservancy and has established the area as a unit within the National Wildlife Refuge System. In addition, Devils Hole is protected as part of Death Valley National Monument. The Ash Meadows area is, located about 40 kilometers (25 miles) from Yucca Mountain. Relict populations of pupfish and many unusual endemic plants exist in the spring habitats of Ash Meadows including: four species of fish listed as endangered by the USFWS, Devils Hole pupfish, Cyprinodon diabolis; Warm Springs pupfish, Cyprinodon nevadensis pectoralis; Ash Meadows Amargosa pupfish, Cyprinodon nevadensis mionectes; and Ash Meadows speckled dace, Rhinichthys osculus nevadensis (USFWS, 1983a); an endangered plant, Amargosa niterwort, Nitrophila mohavensis; six threatened plants, Ash Meadows ivesia, Ivesia eremica; Ash Meadows sunray, Enceliopsis nudicaulis var. corrugata; spring-loving centaury, Centaurium namophilum; Ash Meadows blazing star, Mentzelia leucophylla; Ash Meadows milk vetch, Astragalus phoenix; and Ash Meadows gumplant, Grindelia fraxinoprattensis; and a threatened insect, Ash Meadows naucorid, Ambrysus amargosus (DOI, 1984). Eight species of endemic molluscs are candidates for possible listing as endangered or threatened species in the future (DOI, 1984), and the Ash Meadows vole (Microtus montanus nevadensis) has been classified as a Category 2 mammal which is being reviewed for possible addition to the list (DOI, 1984).

Analysis of studies by Dudley and Larson (1976) and Waddell (1982) suggest that the construction and operation of a repository at Yucca Mountain will not affect the outflow of the springs at Ash Meadows, because water supplies for the repository will not be drawn from the ground-water basin that feeds the springs. Potential environmental impacts to this refuge from repository workers are projected to be negligible because land use in the area would be restricted by the USFWS.

Conclusion

The proposed repository and its supporting facilities, including a rail line that may be constructed in southern Nevada and a paved road that may be

constructed from U.S. Highway 95 northward to Yucca Mountain, would not result in any significant adverse environmental effects on federally protected lands (e.g., parks, monuments, recreation areas, wildlife areas, wilderness areas), or lands administered by the U.S. Forest Service. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(4) Proximity to, and projected significant adverse environmental impacts of the repository or its support facilities on, a significant State or regional protected resource area, such as a State park, a wildlife area, or a historical area.

Evaluation

The surface and underground facilities at Yucca Mountain would be located entirely on Federal lands currently administered by the DOE and the DAF, as well as public-domain lands under the jurisdiction of the BLM (Lutsey and Nichols, 1972). If a repository is constructed at Yucca Mountain, a 161-kilometer (100-mile) rail line may be built to the site from Dike Siding a few miles northeast of Las Vegas. The proposed rail line would pass within 1.4 kilometers (0.9 miles) of Floyd R. Lamb State Park (formerly called Tule Springs Park; sections 3, 4, and 9, T. 19 S., R. 60 E.). The composite annual day and night (L_{dn}) noise levels induced in the park by the construction and the operation of the rail line would be below U.S. Environmental Protection Agency limits (Section 5.2.6.1). Therefore, significant adverse impacts to this State Park are not expected from the construction and operation of a rail line in this area.

Conclusion

The repository and its proposed supporting facilities, including a railroad that would be constructed in southern Nevada and a paved road that would be constructed from U.S. Highway 95 northward to Yucca Mountain, would not exert significant adverse environmental impacts on State protected lands, such as parks, recreation areas, or wildlife areas. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(5) Proximity to, and projected significant adverse environmental impacts of the repository and its support facilities on, a significant Native American resource, such as a major Indian religious site, or other sites of unique cultural interest.

Evaluation

Most of the Yucca Mountain site has been surveyed for cultural artifacts by Pippin et al. (1982). Limited test excavations were conducted of 178 prehistoric and 6 historic sites (Pippin, 1984), many of which consist of only flakes and scattered debris. Archaeological surveys have not yet been conducted along the proposed railroad corridor or along the paved road that would be constructed to Yucca Mountain from U.S. Highway 95.

Artifacts at those sites that cannot be preserved during siting and construction, or protected during operation will, upon approval of the Nevada

State Historic Preservation Office, be collected and catalogued. These artifacts, along with a record of the physical setting where they were found, can then be described and displayed in museums. Thus, although some sites may be affected by the construction of the repository, the artifacts and information contained at these sites will be recorded and preserved.

Conclusion

The siting, construction, and operation of the repository are not expected to have an effect on significant Native American resources or unique cultural resources in this region. Although some archaeological and historical sites may be affected by the construction of the repository, the Nevada State Historical Preservation Office will be informed before construction begins so that artifacts at these sites can be collected and catalogued. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(6) Presence of critical habitats for threatened or endangered species that may be compromised by the repository or its support facilities.

Evaluation

Surveys to date indicate that no threatened or endangered plant or animal species, or their critical habitats, occur in the Yucca Mountain area, although a State protected species is found in the area.

Two species found in the Yucca Mountain area (O'Farrell and Collins, 1983) are currently under review by the USFWS as candidates for inclusion in the Federal list of threatened species. They are the Mojave fishhook cactus (Sclerocactus polyancistrus) and the desert tortoise (Gopherus agassizii). The desert tortoise is also a State protected species and is designated as a rare species. Also, preliminary analyses show that the desert tortoise population in the Yucca Mountain area is low in comparison with other areas in the southwestern United States (O'Farrell and Collins, 1983). During repository construction and operation individual tortoises may be transported from the disturbed areas to remote undisturbed locations. The survival of these relocated animals, however, is uncertain, and some of the habitat for the species would be destroyed during repository construction. Efforts consistent with economic and safety considerations will be made to avoid dense populations of the cactus and important habitats for the tortoise. The technique for relocating tortoises will be investigated further before any relocation occurs.

As discussed in the evaluation of potentially adverse condition 3, several species have been listed as threatened or endangered, and others in Ash Meadows have been proposed for future listing. Analyses of studies by Dudley and Larson (1976) and Waddell (1982) suggest that repository siting, construction, operation, and closure at Yucca Mountain should not affect the outflow of the springs in Ash Meadows. Water supplies for the repository will not be drawn from the ground-water basin that feeds the springs. Existing land-use restrictions in the area surrounding the springs and in the ground-water basin that supplies the springs should prevent indirect impacts

on the water supply from workers moving into the area and also should help to protect the habitats of the proposed endangered species.

Conclusion

The siting, construction, and operation of a repository and its supporting facilities are not expected to have a significant adverse effect on the Mojave fishhook cactus, the desert tortoise, or the Ash Meadows ecosystem. In addition, present land-use restrictions in Ash Meadows and regulation of the surrounding ground-water basin will help to protect the habitat of the endangered species found there. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

6.2.1.6.5 Disqualifying conditions

There are three disqualifying conditions with regard to environmental quality. The disqualifying conditions in this guideline (stated below) are evaluated together to avoid repetition. Separate conclusions are given for each disqualifying condition.

Any of the following conditions shall disqualify a site:

- (1) During repository siting, construction, operation, closure, or decommissioning, the quality of the environment in the affected area could not be adequately protected or projected environmental impacts in the affected area could not be mitigated to an acceptable degree, taking into account programmatic, technical, social, economic, and environmental factors.
- (2) Any part of the restricted area or repository support facilities would be located within the boundaries of a component of the National Park System, the National Wildlife Refuge System, the National Wilderness Preservation System, or the National Wild and Scenic Rivers System.
- (3) The presence of the restricted area or the repository support facilities would conflict irreconcilably with the previously designated resource-preservation use of a component of the National Park System, the National Wildlife Refuge System, the National Wilderness Preservation System, the National Wild and Scenic Rivers System, or National Forest Lands, or any comparably significant State protected resource that was dedicated to resource preservation at the time of the enactment of the Act.

Evaluation

The adverse environmental impacts that may be associated with the siting, construction, operation, closure, and decommissioning of a repository at Yucca Mountain are thoroughly described in chapters 4 and 5. The major

impact associated with site-characterization activities would be the disturbance of approximately 285 hectares (705 acres) of wildlife habitat. The impacts related to the repository include (1) the disruption of over 680 hectares (1,680 acres) of desert habitat, (2) fugitive-dust emissions, (3) vehicle emissions, and (4) radiation releases during the excavation and the operation of the repository and possibly from accidents at the repository.

Approximately 680 hectares (1,680 acres) of land will be cleared for the repository and for the supporting transportation facilities in southern Nevada. Surveys to date (O'Farrell and Collins, 1983) indicate that no threatened or endangered plant or animal species, or their critical habitats, occur in the immediate area of the Yucca Mountain site. However, the Mojave fishhook cactus (Sclerocactus polyancistrus) and the desert tortoise (Gopherus agassizii), which are found in the Yucca Mountain area, are currently under review by the U.S. Fish and Wildlife Service (USFWS) as candidates for inclusion in the Federal list of threatened species. The desert tortoise is also a State protected species and is designated as a rare species. Preliminary analyses show that the desert tortoise population is low in the area of the Yucca Mountain site. Tens of thousands of acres of undisturbed habitat will surround the repository site. During repository siting, construction, operation, and closure, individual tortoises may be transported to remote undisturbed locations. Where possible, populations of the cactus and locations of known tortoise habitat identified during preconstruction surveys will be avoided.

Fugitive-dust emissions will result from surface preparation, excavation, and the manipulation of the excavated soil and rocks during siting, construction, operation, closure, and decommissioning. Dust emissions will also result from the disturbance of approximately 486 hectares (1,200 acres) during the construction of a rail line to the repository and the disturbance of 79 hectares (195 acres) during construction of an access road from U.S. Highway 95. During repository construction, the emission rate and predicted impacts for particulates, carbon monoxide, and oxides of sulfur and nitrogen are not expected to exceed the air-quality limits of 40 CFR Part 50 (1983) at the boundary of the controlled area. Table 5-14 and Section 5.2.5 discuss pollutants expected from repository construction, assuming no dust-suppression measures are taken. Total suspended particulates of 130 micrograms per cubic meter are estimated for a ridge location, and 132 micrograms per cubic meter are estimated for a valley location. These concentrations are below the total suspended particulate standards in 40 CFR Part 50 (1983) which specify that a maximum allowable 24-hour concentration of 260 micrograms per cubic meter should not be exceeded more than once per year. Section 5.2.5 provides a more complete discussion of air-quality regulations and estimated impacts. If the Project is subject to Prevention of Significant Deterioration provisions of the Clean Air Act Amendments of 1977, the predicted pollutant concentrations would violate none of the applicable standards.

The release of naturally occurring radon and decay products from the volcanic rocks of the Yucca Mountain site will increase during repository excavation and during the manipulation of the excavated rock and earth. Using estimates of natural radiation in granite (DOE, 1980a), an estimate of the release of natural radioactivity from the volcanic rocks of the Yucca

Mountain site during construction can be calculated. Construction of a repository would result in an annual effective whole-body dose for a member of the general population of less than 0.05 millirem. Natural background radiation from all sources contributes an individual whole-body equivalent dose of 0.09 rem per year (Jackson et al., 1984). Routine releases of radon from the excavated rock and earth during backfilling are expected to be negligible. On the basis of the above estimates, the environmental impacts from radiological releases during excavation are not expected to be significant. Section 6.4.1 discusses radioactive releases during normal repository operations. The largest release is predicted for krypton-85 (see Table 6-46), giving an air concentration of 6.3×10^{-8} curies per cubic meter which represents only 0.009 percent of the maximum permissible concentrations specified in 10 CFR Part 20 (1984). Dispersion between the discharge point and the site boundary would reduce the krypton-85 concentration to below the maximum permissible concentration specified in 10 CFR Part 20 (1984).

The surface and underground facilities at Yucca Mountain would be located entirely on Federal lands currently administered by the U.S. Department of Energy (DOE) and the Department of the Air Force, as well as public-domain lands under the jurisdiction of the Bureau of Land Management. None of these lands are protected for environmental reasons. A railroad may be constructed from Dike Siding, 18 kilometers (11 miles) northeast of Las Vegas, to Yucca Mountain. At some localities along this proposed route, the rail line would be within a few miles of the southern boundary of the Desert National Wildlife Range, part of which has been administratively endorsed as suitable for inclusion in the National Wilderness Preservation System. The effects exerted on the wildlife range by construction and operation of the railroad, even assuming that part of the range is ultimately included in the Wilderness Preservation System, are expected to be insignificant because the rail line is not expected to cross the range.

The boundary of the Death Valley National Monument lies 30 to 40 kilometers (20 to 25 miles) west and southwest of the Yucca Mountain site. The environmental effects of siting, constructing, operating, closing, and decommissioning a repository at Yucca Mountain include increased use of the monument by the construction workers and the employees of the repository. Ash Meadows, located about 40 kilometers (25 miles) from Yucca Mountain, contains plants and animals which have been listed as threatened or endangered species by the USFWS, as well as species proposed for future listing as threatened or endangered species. The outflow of the springs at Ash Meadows is not expected to be affected by the construction and operation of a repository at Yucca Mountain because water supplies for the site will be extracted from a different ground-water basin, as shown by the regional flow models given by Waddell (1982). The USFWS recently purchased 5,121 hectares (12,654 acres) of land in the vicinity of Devils Hole and established this land as a unit within the National Wildlife Refuge System. This action should serve to further restrict potential land use by repository workers in the Ash Meadows area.

The northern part of the controlled area surrounding the repository site would be approximately 8 kilometers (5 miles) south of the Timber Mountain Caldera National Natural Landmark. This federally designated landmark would not be disturbed during the construction and operation of the repository.

Furthermore, because the landmark is located within the Nellis Air Force Range and the Nevada Test Site, access to it has been, and will continue to be, restricted. The northern part of the Toiyabe National Forest is about 80 kilometers (50 miles) southeast of the Yucca Mountain site. It is unlikely that this National forest will be affected by repository development because of its distance from Yucca Mountain.

Conclusion for disqualifying condition 1

On the basis of preliminary evaluations, the siting, construction, operation, closure, and decommissioning of a repository at Yucca Mountain would not result in any unacceptable adverse environmental impacts that could not be mitigated to an acceptable degree. Therefore, the evidence does not support a finding that the site is disqualified (level 1).

Conclusion for disqualifying condition 2

Neither the restricted area nor the supporting facilities for a repository at Yucca Mountain would be located within the boundaries of the National Park System, the National Wildlife Refuge System, the National Wilderness Preservation System, or the Wild and Scenic Rivers System. Therefore, the evidence supports a finding that the site is not disqualified on the basis of that evidence and is not likely to be disqualified (level 1).

Conclusion for disqualifying condition 3

Neither the restricted area nor the supporting facilities for a repository at Yucca Mountain would irreconcilably conflict with the previously designated resource-preservation use of a component of the National Park System, the National Wildlife Refuge System, the National Wilderness Preservation System, the National Wild and Scenic Rivers System, or National Forest Lands, or any comparably significant State protected resource. Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is disqualified (level 1).

6.2.1.6.6 Evaluation and conclusion for the qualifying condition on the environmental quality guidelines

Evaluation

Chapters 4 and 5 provide preliminary assessments of the potential for adverse environmental impacts from the siting, construction, operation, closure, and decommissioning of a repository at Yucca Mountain. These preliminary studies indicate that no potentially significant adverse environmental impacts that could not be mitigated to an acceptable degree should be expected from the siting, construction, operation, closure, and decommissioning of a repository at Yucca Mountain. The quality of the environment during this and future generations can be adequately protected. Estimates of radiation releases during normal operation and worst-case accident scenarios provide confidence that the public and the environment can be adequately protected from the potential hazards of radioactive-waste disposal.

No major conflict with applicable Federal, State, and local environmental requirements is expected. The adverse environmental impacts expected from repository siting, construction, operation, closure, and decommissioning can either be avoided or mitigated to an acceptable degree by reasonable and inexpensive methods. The repository and its supporting facilities, including a rail line and roads, would not result in any significant adverse environmental impacts on Federal or State protected lands or any known threatened or endangered species or their habitats.

Conclusion

The environment can be protected during the siting, construction, operation, closure, and decommissioning of a repository at Yucca Mountain. No potentially significant adverse environmental impacts have been identified. The requirements specified in 10 CFR 960.5-1(a)(2) (1984) for protection of the public and the environment from the potential hazards posed by the disposal of radioactive waste are expected to be met without undue difficulty. Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition for environmental quality (level 3).

6.2.1.7 Socioeconomic impacts (10 CFR 960.5-2-6)

6.2.1.7.1 Introduction

The qualifying condition for this guideline is as follows:

The site shall be located such that (1) any significant adverse social and/or economic impacts induced in communities and surrounding regions by repository siting, construction, operation, closure, and decommissioning can be offset by reasonable mitigation or compensation, as determined by a process of analysis, planning, and consultation among the DOE, affected State and local government jurisdictions, and affected Indian tribes; and (2) the requirements specified in Section 960.5-1(a)(2) can be met.

The preclosure socioeconomics technical guideline is concerned with (1) the interaction between repository-related activities and the existing economic, demographic, and social conditions of the area during the siting, construction, operation, closure, and decommissioning of the repository and (2) the reasonable mitigation or compensation for associated significant adverse impacts.

The guideline contains four favorable conditions, four potentially adverse conditions, one disqualifying condition, and one qualifying condition. Table 6-11 summarizes the pertinent findings for all conditions except the disqualifying condition.

Table 6-11. Summary of analyses for Section 6.2.1.7; socioeconomic impacts (10 CFR 960.5-2-6)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITIONS	
(1) Ability of an affected area to absorb the project-related population changes without significant disruptions of community services and without significant impacts on housing supply and demand.	The evidence indicates that this favorable condition is present at Yucca Mountain: projected population growth rates with the repository do not exceed historical rates; the area is expected to absorb changes without significant impacts.
(2) Availability of an adequate labor force in the affected area.	The evidence indicates that this favorable condition is not present at Yucca Mountain: an adequate total work force is expected to be available; the available work force with mining skills is expected to be inadequate; it is possible that the available construction work force may also be inadequate.
(3) Projected net increases in employment and business sales, improved community services, and increased government revenues in the affected area.	The evidence indicates that this favorable condition is present at Yucca Mountain: the affected area is projected to have increased employment and business sales; community services could be improved and government revenues are likely to increase.
(4) No projected substantial disruption of primary sectors of the economy of the affected area.	The evidence indicates that this favorable condition is present at Yucca Mountain: increased employment in the mining and construction sectors is not expected to cause substantial disruption; results of a preliminary study concerning the potential effect of a repository on tourism are inconclusive. However, analysis to date of cases examining the relationship of safety concerns to tourism concluded that long-term impacts were not apparent.

Table 6-11. Summary of analyses for Section 6.2.1.7; socioeconomic impacts (10 CFR 960.5-2-6) (continued)

Condition	Department of Energy (DOE) finding
<p>POTENTIALLY ADVERSE CONDITIONS</p>	
(1) Potential for significant repository-related impacts on community services, housing supply and demand, and the finances of State and local government agencies in the affected area.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: service providers in the area are expected to have the resources to deal with community-level population growth rates, which are generally expected to be within the range experienced historically by urban communities and the two counties; significant repository-related impacts on government finances are, accordingly, not expected.
(2) Lack of an adequate labor force in the affected area.	The evidence indicates that this potentially adverse condition is present at Yucca Mountain: the available mining work force is expected to be inadequate; it is possible that the construction work force may be also; the total work force is expected to be adequate.
(3) Need for repository-related purchase or acquisition of water rights, if such rights could have significant adverse impacts on the present or future development of the affected area.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: DOE water rights are expected to provide sufficient water to support repository activities without adverse impacts on the rights of other water users in the region.

Table 6-11. Summary of analyses for Section 6.2.1.7; socioeconomic impacts (10 CFR 960.5-2-6) (continued)

Condition	Department of Energy (DOE) finding
POTENTIALLY ADVERSE CONDITIONS (continued)	
(4) Potential for major disruptions of primary sectors of the economy of the affected area.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: information available to date does not suggest that the repository is likely to have significant effects on tourism; the expected increase in mining and construction employment is not considered to be a major disruption.
QUALIFYING CONDITION	
The site shall be located such that (1) any significant adverse social and/or economic impacts induced in communities and surrounding regions by repository siting, construction, operation, closure, and decommissioning can be offset by reasonable mitigation or compensation, as determined by a process of analysis, planning, and consulting among the DOE, affected State and local government jurisdictions, and affected Indian Tribes; and, (2) the requirements specified in Section 960.5-1(a)(2) can be met.	Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): no unmitigatable significant adverse social and/or economic effects have been identified in preliminary design and impact studies; the DOE is committed to working with State and local governments so that the public and the environment are protected from the hazards posed by the disposal of radioactive waste.

6.2.1.7.2 Data relevant to the evaluation

Preliminary evaluations of the socioeconomic impacts of siting, construction, operation, closure and decommissioning of a repository at Yucca Mountain are discussed in chapters 4 and 5. For purposes of this guideline, the affected region is defined to include Nye County, where the site is located, as well as neighboring Clark County. The U.S. Department of Energy intends to consider a larger geographic area in its studies of potential impacts, if Yucca Mountain is nominated and approved for site characterization. However, the socioeconomic effects predicted for the two counties, where approximately 96 percent of the repository-related population are expected to settle, are indicative of the nature and extent of the total social and economic impact.

Information about the potential social and economic impacts of a repository at Yucca Mountain is contained in preliminary reports (McBrien and Jones, 1984; SAIC, 1985) describing previous and ongoing work on the regional and local impacts, including potential impacts on local tourism. The analyses and data in those reports as well as the analyses and data presented in chapters 3, 4, and 5 provide the basis for assessing the potential social and economic impacts of a repository at Yucca Mountain.

Assumptions and data uncertainties

The assumptions and analyses that form the basis for this evaluation appear in detail in sections 3.6, and 4.2.2, 5.1.5, and 5.4.

6.2.1.7.3 Favorable conditions

- (1) Ability of an affected area to absorb the project-related population changes without significant disruptions of community services and without significant impacts on housing supply and demand.

Evaluation

Detailed forecasts of community-level service capacity and housing supply and demand are not available. This evaluation considers impacts at the county level. Subsequent analyses will consider, in more detail, impacts on the incorporated cities in the biconity area, and on other governmental units responsible for providing public services. Although it is recognized that the term significant disruptions may be defined differently by the U.S. Department of Energy (DOE) and local communities, for purposes of this analysis, county-level population changes were assumed to significantly affect community services and housing when the total population (baseline plus repository-related) increase in any year exceeds that historically experienced by the area.

In general the construction of the repository would require more workers and thus result in greater population increases than would the siting, operation, and decommissioning. However, because of the two-stage repository design, the construction and operation periods are expected to overlap

3 years. The maximum number of workers (approximately 1,900) would be needed in the sixth year of construction, which is also the first year of operations (1998) (Table 5-5a). The maximum 1-year percent increase in population would occur during the second year of construction (1994) (Table 5-47). This maximum 1-year increase is projected to be 3.7 percent for Clark County and 4.0 percent for Nye County. Without the repository, the population growth rate between 1993 and 1994 is projected to be 3.1 percent for Clark County and 2.1 percent for Nye County. Given previous population growth rates (tables 3-16 and 3-15), the affected area is expected to be able to absorb the repository-related population changes without significant disruptions in community services or significant impacts on housing supply and demand. As population increases, with or without the repository, certain areas of both counties are expected to experience water-supply problems (Section 5.4.3.3).

Evaluations of the extent and significance of future impacts are made through comparisons with past growth rates. These evaluations assume either that the historical growth did not result in significant impacts on housing and community services or that the responsible local governments have benefited from experience so that significant future impacts on community services and housing can be avoided. It is assumed that the DOE would work in cooperation with the responsible governmental entities to plan for increased demand for community services and housing and to develop monitoring, corrective action, and mitigation programs, which would include the provision of financial assistance as specified by the Nuclear Waste Policy Act (NWPA, 1983).

While past population growth provides the responsible governmental entities and the private sector with experience in planning for, and responding to, future growth, some impacts on housing and community services may occur regardless of the ability of these organizations to respond. These impacts may involve aesthetics; for example, a change in housing mix (e.g., more mobile homes) associated with growth may be regarded as undesirable by some community residents. Such aesthetic preferences are not uniform across communities. Individual community preferences will be explored in future research. As appropriate, the DOE, in consultation with local officials, would develop a plan to encourage or discourage workers from moving into specific communities. For example, this plan might include transportation subsidies for repository employees commuting along specific routes or the provision of housing.

Conclusion

The affected area, including the Las Vegas Valley, has the ability to absorb the repository-related population changes without significant disruptions of community services and without significant impacts on housing supply and demand. This conclusion is based on the assumption that no 1-year population growth rate expected during the repository project would exceed historical population growth rates in the affected (i.e. bicounty) area. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(2) Availability of an adequate labor force in the affected area.

Evaluation

The peak number of direct workers expected during site characterization is 273. Approximately 60 percent of those are expected to be existing DOE and contractor employees (Section 4.2.2.1.1). The demand for additional site characterization workers from the existing work force is not expected to be significant. At peak, the repository construction/operation overlap would employ about 1,900 direct workers in 1998. One approach for evaluating the adequacy of labor force is to compare the total repository labor requirement with the size of the projected baseline work force. This number of direct workers is less than 1 percent of the estimated bicoounty wage and salary employment (see Section 5.4.1.1). This comparison indicates that the available baseline work force would be adequate, although the mix of skills available may not adequately reflect project needs. However, baseline projections indicate that the region will contain significant numbers of workers with many of the skills required for a repository (Section 3.6.1).

Preliminary estimates of labor requirements indicate that at the peak of construction, the repository would increase regional construction employment by about 700 workers, which is approximately 3 percent of projected baseline bicoounty construction employment in 1995 (Section 5.4.1.1). If vertical emplacement is used, mining employment (assumed to include mining support workers) would increase by about 40 percent over the projected Nye County baseline in 1995. Mining employment would decline to about 400 in 1998. This employment level would be maintained for about 20 years and represents approximately a 23 percent increase over mining employment projected for Nye County in the year 2000. While horizontal emplacement would require about 80 percent as many mining workers as vertical emplacement, the construction work force requirement would be about the same for both (Section 5.4.1.1). Thus, the development of a repository would place significant demands on the local mining sector and moderate demands on the local construction sector. Consequently, many mining and some construction workers would be drawn from outside the bicoounty area. The extent of this immigration would depend on the presence of other large projects in the early 1990s, the state of the national economy at that time, and the unemployment rates in those skill areas.

In summary, the total labor requirement of the repository appears small in comparison with the projected bicoounty work force. However, although an adequate baseline work force would probably be available, it is likely that the available mining work force would be inadequate and it is possible that the construction work force could be also, although to a lesser degree. Thus the development of a repository at Yucca Mountain would lead to the immigration of workers with these and other skills.

Conclusion

The work force in southern Nevada, including the Las Vegas Valley, is sufficiently large to site, construct, and operate a repository at Yucca Mountain. Although an adequate total work force may be available for a repository at Yucca Mountain, the available work force with mining skills would be inadequate and it is possible that the available construction work

force may also be inadequate. Therefore, the evidence indicates that this favorable condition is not present at Yucca Mountain.

(3) Projected net increases in employment and business sales, improved community services, and increased government revenues in the affected area.

Evaluation

Preliminary analyses summarized in sections 4.2.2.1.1 and 5.1.5 indicate that a maximum of about 700 direct and indirect jobs would be created in southern Nevada by site-characterization activities in the late 1980s, and a maximum of about 4,800 direct and indirect jobs would be created by the repository construction and operation in 1998. The potential annual wage-related increases in area income related to repository construction, operation, and decommissioning could reach \$110 million in 1998 under vertical emplacement (Table 5-45). These and other direct and repository-induced expenditures would result in increased State and local government tax revenues, which may be offset by increased outlays.

This favorable condition requires increases in government revenues in the affected area, but it does not require a positive net fiscal balance. However, where State and local government outlays would exceed the revenue generated by the repository, the Federal Government would take action to provide financial assistance (Section 5.4.5). As a result, incremental State and local government outlays would not exceed incremental revenues and might actually be less. Additional data and analysis would be required to quantify the potential fiscal effects and appropriate levels of financial assistance.

In recent years, most community services in Clark and Nye counties have expanded to meet the needs of the area's rapidly growing population. Thus it is reasonable to expect that the community-services demand of repository-related workers and their dependents would result in an increase in these services, especially since local government revenues are expected to increase. It is also possible that the repository project could increase the quality of community services. For example, old facilities could be replaced by new facilities to serve a larger population, the increased population could support more diverse community services, and facilities could be acquired that would not otherwise be developed. Thus, the impact on the quality of community services would not necessarily be negative and could be positive.

In summary, preliminary analyses indicate that a repository at Yucca Mountain would result in projected net increases in employment and business sales and could result in improved community services and increased government revenues in the affected (i.e. bicounty) area. It is assumed that the DOE would work with State and local governmental entities to identify potential adverse fiscal effects requiring mitigation and that Federal financial and technical assistance would be provided, if necessary, to offset such potential effects. The fiscal effects include the increased spending by State and local entities responsible for providing community services.

Conclusion

A repository at Yucca Mountain would increase employment opportunities and business sales in southern Nevada. Community services could be improved, and government revenues are likely to increase. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

- (4) No projected substantial disruption of primary sectors of the economy of the affected area.

Evaluation

A primary or basic sector of the economy is one that produces goods sold outside the region. Interest in such sectors stems from the assumption that regional growth is intimately tied to the growth of primary sectors. Expansion of the primary sector is assumed to result in increased production by secondary, or support, sectors of the economy. Preliminary analyses indicate that in Clark and Nye counties, the important primary sectors are tourism and mining, respectively. Employment impacts of site characterization on these sectors are expected to be insignificant.

Even though repository-related increases in population may have a small positive effect on tourism, analyses to date have investigated only potential negative impacts. Preliminary results to date concerning the potential effect of repository operation on tourism are inconclusive (Section 5.4.1.6). However, preliminary analyses of cases examining the relationship of nuclear and non-nuclear safety concerns to tourism concluded that long term impacts on tourism were not apparent. Because of public concern about impacts on tourism, the importance of the tourism sector to the local and State economies, and the preliminary nature of the available data, this issue will be the subject of continued research.

Under vertical emplacement, repository mining employment would increase from a 1993 level of about 105 to a peak of about 630 in 1995 and 1996. This would represent nearly a 40 percent increase over projected Nye County baseline mining employment in 1995. Repository mining workers would be sustained at about 400 from 1998 to 2018. This number of workers would represent about a 23 percent increase over mining employment projected for Nye County in the year 2000 (see Section 5.4.1.1). Thus, the impact of the repository on mining employment is considered to favorably affect this primary sector of the economy. However, there may be secondary disruptive impacts due to worker relocation or increased labor costs.

Conclusion

The primary sectors of the economy in southern Nevada are tourism and mining. The employment impacts of site characterization on these sectors are expected to be insignificant. Information available to date does not suggest that the repository construction and operation would significantly affect tourism. Construction and operation of a repository would significantly increase employment in mining. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

6.2.1.7.4 Potentially adverse conditions

- (1) Potential for significant repository-related impacts on community services, housing supply and demand, and the finances of State and local government agencies in the affected area.

Evaluation

In evaluating this potentially adverse condition, the U.S. Department of Energy (DOE) conducted a coarse screening so that detailed studies would not be undertaken for sites which ultimately would not be chosen for site characterization. Detailed quantitative information on current and projected levels of community services is not readily available. However, repository-related population growth rates are indirect indicators of the potential for community services and housing impacts. Qualitative information can also be used to evaluate service providers' potential capabilities to accommodate repository-related population growth. By limiting the analysis of this potentially adverse condition to estimated population growth rates with the repository, and qualitative information on community service providers, it was possible to use readily available information and avoid giving a false impression of precision, which could result from combining a more sophisticated analytical approach with insufficient data.

If service providers are unable to furnish, in a timely manner, the services and housing required by residents of the communities in which repository-related workers are expected to settle, impacts may be perceived by those residents. Generally, community services in the unincorporated towns nearest the repository site (i.e. Amargosa Valley, Beatty, Indian Springs, and Pahrump) are not provided by town governments. Instead, services are provided by the Nye and Clark county commissions, county-wide agencies (e.g. the Nye and Clark county school districts), local special purpose districts (e.g. the Beatty Water and Sanitation District), and voluntary organizations (e.g. Amargosa Volunteer Fire Department). With only a few exceptions, water in the unincorporated towns near the repository site is supplied by private wells and waste water is disposed in private septic tanks and leach fields (sections 3.6.3.3 and 3.6.3.4).

Housing in rural southern Nevada is provided almost entirely by the private sector. Ample land for expansion of housing is available in the rural towns closest to the repository site. In Indian Springs, for example, where most of the housing stock consists of mobile homes, the most recent land use plan for the community allows for approximately a fourfold increase in residential land use, much of it at higher densities than at present (Clark County Department of Comprehensive Planning, 1980).

Repository-related population increases during site characterization are not expected to significantly affect community services. The 1-year growth rate of the total population with the repository (i.e., baseline population plus estimated repository-related population) is used in this analysis of repository construction, operation and decommissioning. The total population growth rate is defined as the percentage change in the total population in 1-year relative to that in the previous year. These growth rates vary with changes in the number of direct workers (shown in tables 5-5a and 5-5b). In

the absence of detailed baseline community population forecasts, it was assumed that each community would retain its base year share of the county population shown in tables 3-15 and 3-16 (population values for years not shown in those tables were estimated by linear interpolation). Because of community population data availability, the base years for Clark and Nye county communities were 1980 and 1984, respectively (See Clark County Department of Comprehensive Planning, 1983; and Smith and Coogan, 1984). Indian Springs, in Clark County, was assumed to retain its 1980 share of the civilian population, and the number of military personnel were assumed to remain at the level estimated for 1980.

For purposes of this analysis, communities were grouped according to community ZIP code data reported by recent Nevada Test Site (NTS) workers and summarized in Table 5-26. Percentages reported in that table were used to estimate the size of the vertical emplacement repository-related maximum population increase (shown in Table 5-47) expected to settle in each community. This method is similar to that used in Section 4.2.2.2 to estimate the size of the maximum site-characterization-related population expected to settle in each community. The historical population used in that analysis, and shown in Table 4-5, is the base year population used in this analysis.

The maximum 1-year growth rate of the total community population with the repository (i.e., baseline population plus estimated repository-related population) was used as an indicator of the potential for impacts on community services, housing, and fiscal conditions, since these depend directly or indirectly on population. This maximum rate occurs between 1993 and 1994. Maximum 1-year community population growth rates have been estimated to be: 3.7 percent in unincorporated urban Clark County and Las Vegas, 3.9 percent in North Las Vegas, 13.2 percent in Indian Springs, 3.6 percent in Henderson, 3.3 percent in Boulder City, 5.0 percent in Pahrump, 4.1 percent in Tonopah, 2.4 percent in Beatty, and 2.5 percent in Amargosa Valley.

Growth rates estimated above for the urban areas of Clark County are generally within the range of those experienced historically (approximately 2.7 to 13.2 percent) by those urban communities (DOC, 1981) and their municipal service providers. Section 5.4.5 indicates that fiscal effects of community service impacts in these areas are expected to be observable, yet insignificant.

In Amargosa Valley and Beatty, town government consists of advisory councils. Indian Springs has a town advisory board and Pahrump has recently established a town board. Governmental organizations in these unincorporated towns have limited powers and resources related to community services. Although community-specific service and housing demands could increase at rates proportional to the maximum 1-year community population growth rates presented above, the potential impacts would be mainly on county-wide service providers that are more likely to have resources for managing growth.

Conclusion

Negative impacts on community services, housing supply and demand, and the finances of State and local government agencies in the affected area are

not expected to be significant for repository siting, construction, operation, and decommissioning. Although community-specific service and housing demands could increase at rates proportional to the maximum 1-year community population growth rates estimated with the repository, these rates are generally within the range of those experienced historically by the urban communities and their municipal service providers. Because the unincorporated towns nearest the Yucca Mountain site have limited powers dealing with community services, potential population growth in these communities would generally impact county-wide service providers. These service providers are more likely to have resources for managing growth. Additionally, the community level growth rates estimated for the unincorporated towns are generally within the range of those experienced historically by Nye and Clark counties (tables 3-15 and 3-16). Ample land is available for housing in the rural communities closest to the Yucca Mountain site. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(2) Lack of an adequate labor force in the affected area.

Evaluation

The availability of an adequate labor force in the affected area is discussed under favorable condition 2.

Conclusion

Although an adequate total work force would probably be available for a repository at Yucca Mountain, the available mining work force would be inadequate and it is possible that the construction work force could be also. Therefore, evidence indicates that this potentially adverse condition is present at Yucca Mountain.

(3) Need for repository-related purchase or acquisition of water rights, if such rights could have significant adverse impacts on the present or future development of the affected area.

Evaluation

According to preliminary analyses, the repository will require about 432,000 cubic meters (350 acre-feet) of water per year over a 32-year period which includes the construction period and the emplacement phase assuming vertical emplacement (Morales, 1985). This rate and quantity of withdrawal should not impinge on known water rights and should not affect other water users in the region (see favorable condition 2 in Section 6.3.1.1). The Alkali Flat-Furnace Creek Ranch ground-water basin in which Yucca Mountain is located contains no major developments or population centers that would compete with the repository for ground water. Analyses to date conclude that sufficient water to support the repository can be obtained from new or existing wells at the NTS (Section 6.3.3.3) for which the DOE has existing water rights.

Secondary effects on local water systems from the increased demand associated with population increases are expected to be minimal. Land-use restrictions through the granting of water permits by the Office of the State

Engineer of Nevada will also help to plan for and to minimize effects on local aquifers. Some communities may require financial or technical assistance to expand their water delivery systems to meet demands of repository related population growth. The Las Vegas valley is projected to have water-supply problems by the year 2020, even without the population increases resulting from development of the repository (Section 5.4.3.3). Local officials are evaluating alternatives to alleviate this problem.

Conclusion

Preliminary analyses of water supply and demand indicate repository-related water use will not have significant adverse impacts on present or future development in the region surrounding Yucca Mountain. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(4) Potential for major disruptions of primary sectors of the economy of the affected area.

Evaluation

The absence of any projected substantial disruption of the primary sectors of the economy of the affected area is discussed under favorable condition 4.

Conclusion

The primary sectors of the economy in southern Nevada are tourism and mining. Information available to date does not suggest that the repository is likely to have significant effects on tourism. It would increase employment in construction and significantly increase employment in mining. This increase is not considered to be a major disruption. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

6.2.1.7.5 Disqualifying condition

A site shall be disqualified if repository construction, operation, or closure would significantly degrade the quality, or significantly reduce the quantity, of water from major sources of offsite supplies presently suitable for human consumption or crop irrigation and such impacts cannot be compensated for, or mitigated by, reasonable measures.

Evaluation

Repository construction, operation, and closure would increase water consumption through water use at the repository and the use of water by the immigrating population. The effects of this water use are described in sections 5.2.2 and 5.4.3. Because the climate is arid and the water table is deep (more than 200 meters (656 feet) below the repository horizon), it is

extremely unlikely that repository activities could degrade the quality of ground water in the Yucca Mountain region.

Ground water would be the repository water source (see Section 5.1), and competing requirements for ground-water use have been considered. Surface water has not been considered for repository or domestic use, because it is not generally available in this arid region. Well J-13 and the proposed locations of repository surface facilities are on the Nevada Test Site. If a repository is developed at Yucca Mountain, a permanent land withdrawal will be necessary, in accordance with the Federal Land Policy and Management Act of 1976. Reservation of water rights is explicit in the withdrawal, as described in the guideline on site ownership and control (Section 6.2.1.3). The Office of the State Engineer of Nevada has prepared a series of water planning reports, and the second report of the series includes estimates of water withdrawals and consumption by counties and hydrographic regions (Office of the State Engineer, 1971). These estimates provided a basis for projecting future water requirements in Nevada. Estimates of water requirements for the construction, operation, decommissioning, and closure of the repository are based on preliminary conceptual designs. For the first 32 years of repository construction and operation, it is estimated that an average of about 432,000 cubic meters (350 acre-feet) per year of water will be used (Morales, 1985).

The regional effects of withdrawing ground water for a repository at Yucca Mountain are expected to be negligible. Thordarson (1983) reports that the water level in Well J-13 has remained essentially constant after long periods of pumping between 1962 and 1980. The large volume of water produced from this well, along with the evidence of only minor drawdown during pumping tests, suggests that the aquifers underlying Yucca Mountain can yield large quantities of ground water for long periods of time without lowering the regional ground-water table.

Municipal water-supply systems for Nye County and Clark County communities are detailed in Section 3.6.3.3. At present, the size of municipal and private utility systems in most communities near Yucca Mountain appears adequate for current population levels. Several communities have plans for improvements that will require a number of years to complete, such as new wells and water distribution and sewer lines. These plans were designed to accommodate projected baseline growth in the immediate vicinity of the communities. The major problem presently associated with the expansion of water systems is identifying additional potable-water sources and obtaining adequate development capital.

According to an investigation sponsored by the State of Nevada (State of Nevada, NDCNR, 1982), there are both legal and technical uncertainties as to the ability of existing sources to meet the water-supply needs of the Las Vegas valley beyond the year 2020, or when the population reaches about 1 million people, if present rates of water use continue. The increase in water demand due to repository-related population growth may slightly accelerate the time when present sources become inadequate. The analyses in Section 5.4.2 and in favorable condition 1 in this section, indicate that a maximum 1-year population growth rate of about 3.7 percent is expected for Clark County and 4.0 percent is expected for Nye County with the repository. These population growth rates associated with the repository are within the

range of those experienced historically in the bicounty area, and are not likely to significantly aggravate the water-supply situation.

Conclusion

The projected population increases associated with the repository construction and operation are relatively small. However, proper planning is needed to ensure that the expansion of water supplies occurs in a timely manner. The Nuclear Waste Policy Act (NWPA, 1983) provides for financial and technical assistance, which could enable local communities to prepare for increased growth. Repository construction, operation, or closure would not significantly degrade the quality, nor would water use associated with the repository significantly reduce the quantity of water from major sources of offsite supplies presently suitable for human consumption or crop irrigation. Therefore, the evidence does not support a finding that the site is disqualified (level 1).

6.2.1.7.6 Evaluation and conclusion for the qualifying condition on the socioeconomic impacts guideline

Evaluation

An analysis of the adverse impacts of locating a repository at Yucca Mountain must consider the following areas: significant adverse impacts on labor; on the primary or basic sectors of the economy; on direct and indirect employment and business sales; on competition for water resources; on community services; on housing supply and demand; and on public-agency revenues and expenditures. It is assumed that the U.S. Department of Energy (DOE) will take reasonable mitigative or compensatory action under the provisions of the Nuclear Waste Policy Act (the Act) of 1982, if it is needed in these areas (NWPA, 1983).

As discussed in Section 5.4, preliminary analyses of labor demand, materials and resources, income, and land use reveal no potentially significant adverse impacts. It is expected that impacts on State and local community infrastructure discussed in Section 5.4 can be offset by reasonable mitigation or compensation under the financial and technical assistance provisions of the Nuclear Waste Policy Act (NWPA, 1983). The DOE maintains a commitment to consult and cooperate with responsible State and local governments in identifying specific areas where adverse impacts could occur and in developing appropriate measures of corrective action and mitigation (including mitigation by avoidance). Ongoing research and analysis of potential impacts on tourism will further assess the potential for adverse effects of a repository at Yucca Mountain. Further research will examine the potential for impacts on social structure and organization including social problems, culture and lifestyle, and on overall quality of life. No unmitigable significant adverse impacts have been identified in any of these areas.

A summary of the evaluation to date of the socioeconomic impacts of repository siting, construction, and operation, is given in chapters 4 and 5. Future socioeconomic evaluations that are discussed below will be undertaken if the Yucca Mountain site is approved for site characterization. The DOE

will establish a monitoring program to validate the expected socioeconomic impacts of site characterization presented in Chapter 4, and identify mechanisms by which the DOE would determine appropriate and timely corrective action for any unexpected significant adverse social and economic impacts that are identified by that monitoring program. More detailed studies regarding baseline socioeconomic conditions identified in Chapter 3, and the effects of repository construction, operation, decommissioning, and closure presented in Chapter 5 will be undertaken in preparation of an environmental impact statement. If the Yucca Mountain site is selected for development of a repository, plans to monitor repository activities and mitigate socioeconomic impacts would be developed in consultation with State and local governmental representatives. As more specific system-design information becomes available or as impact issues are raised, other means of protecting the socioeconomic welfare--the aggregate well-being of area residents--of the general public in the affected area will be identified.

Conclusion

The siting, construction, operation, decommissioning, and closure of a repository at Yucca Mountain are not expected to generate any significant adverse socioeconomic effects on the surrounding region that cannot be offset by reasonable mitigation or compensation through a process of planning, analysis, and consultation among the DOE, the affected State, and local governmental jurisdictions. This assessment is based on preliminary design and impact studies. Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition for socioeconomic impacts (level 3).

6.2.1.8 Transportation (10 CFR 960.5-2-7)

6.2.1.8.1 Introduction

The qualifying condition for this guideline is as follows:

The site shall be located such that (1) the access routes constructed from existing local highways and railroads to the site (i) will not conflict irreconcilably with the previously designated use of any resource listed in 960.5-2-5(d)(2) and (3); (ii) can be designed and constructed using reasonably available technology; (iii) will not require transportation system components to meet performance standards more stringent than those specified in the applicable DOT and NRC regulations, nor require the development of new packaging containment technology; (iv) will allow transportation operations to be conducted without causing an unacceptable risk to the public or unacceptable environmental impacts, taking into account programmatic, technical, social, economic, and environmental factors; and (2) the requirements of Section 960.5-1(a)(2) can be met.

The objective of the preclosure transportation technical guideline is to ensure that proper consideration is given to the transportation of waste to a

repository site, as it could affect the health and safety of the public, the environment, and the cost of waste disposal. Areas of concern include (1) the construction of access routes from existing local highways and railroads to the site; (2) the improvement and use of existing local highway and railroad networks; (3) projected risks, costs, and other impacts of waste transportation; and (4) compliance with applicable Federal, State, and local regulations.

The guideline contains nine favorable conditions, four potentially adverse conditions, and one qualifying condition. A summary of the evaluations that follow is given in Table 6-12.

6.2.1.8.2 Data relevant to the evaluation

Preliminary design drawings and cost estimates have been used as the basis for evaluating proposed access routes to the Yucca Mountain site from existing regional highways and mainline railroads. A Bureau of Land Management wilderness status map (BLM, 1983) was used to assess the location of these routes in relation to land ownership and resource areas addressed in Section 6.2.1.6, disqualifying conditions 2 and 3.

Atlases published by the Nevada Department of Transportation and Rand McNally were used to calculate distances from the site to regional highways and mainline railroads. Information on railroad interchange points was provided by the Union Pacific Railroad (Nunn, 1983). The costs and risks of transporting radioactive wastes to potential first repository sites in the United States, including Yucca Mountain, are estimated in Appendix A (Transportation).

The statutes and regulations of Nevada and adjoining states were obtained from the legislative data base at the Oak Ridge National Laboratory and from a report issued by the National Conference of State Legislatures (Foster, 1983). They were compared with U.S. Department of Transportation regulations in 49 CFR Part 177 (1983), with 10 CFR 71.5a (1984), and with 10 CFR 73.37 (1984).

Information on emergency response to accidents during radioactive-waste transport in the State of Nevada was obtained from the State of Nevada's Radiological Emergency Response Plan (State of Nevada, Department of Human Resources, 1983) and the U.S. Department of Energy, Nevada Operations Office (DOE/NVO, 1985). Information on regional weather conditions was obtained from publications by the U.S. Department of Commerce (DOC, 1952, 1968), Lineham (1957), Thom (1963), Pautz (1969), Bowen and Egami (1983), Hershfield (1961), and Quiring (1983). Information regarding road closures was obtained from Hill (1985a,b).

The data and methods used to estimate the radiological impacts are described in Appendix A (Transportation). The appendix also describes the computer program used to calculate the impacts and the routing models used to postulate highway and rail travel routes and distances.

Table 6-12. Summary of analyses for Section 6.2.1.8; transportation (10 CFR 960.5-2-7)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITIONS	
(1) Availability of access routes from local existing highways and railroads to the site which have any of the following characteristics.	The evidence indicates that this favorable condition is present at Yucca Mountain: the Yucca Mountain site meets three out of five characteristics; only one is required.
(i) Such routes are relatively short and economical to construct as compared to access routes for other comparable siting options.	Routes will not be relatively short and economical to construct.
(ii) Federal condemnation is not required to acquire rights-of-way for the access routes.	Federal condemnation will not be necessary.
(iii) Cuts, fills, tunnels, or bridges are not required.	Minor cuts and fills and a bridge are required along the access route.
(iv) Such routes are free of sharp curves or steep grades and are not likely to be affected by landslides or rockslides.	No sharp turns or steep grades are required; routes will avoid areas likely to be affected by landslides or rockslides.
(v) Such routes bypass local cities and towns.	Access routes will bypass cities and towns.
(2) Proximity to local highways and railroads that provide access to regional highways and railroads and are adequate to serve the repository without significant upgrading or reconstruction.	The evidence indicates that this favorable condition is present at Yucca Mountain: the local transportation infrastructure will not require upgrading or reconstruction.

Table 6-12. Summary of analyses for Section 6.2.1.8; transportation (10 CFR 960.5-2-7) (continued)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITIONS (continued)	
(3) Proximity to regional highways, mainline railroads, or inland waterways that provide access to the national transportation system.	The evidence indicates that this favorable condition is present at Yucca Mountain: an access road provides direct access to the regional system, and a railspur provides direct access to the mainline railroad.
(4) Availability of a regional railroad system with a minimum number of interchange points at which train crew and equipment changes would be required.	The evidence indicates that this favorable condition is present at Yucca Mountain: a minimum number of interchange points exists for crew and equipment changes.
(5) Total projected life-cycle cost and risk for the transportation of all wastes designated for the repository which are significantly lower than those for comparable siting options, considering locations of present and potential sources of waste, interim storage facilities, and other repositories.	The evidence indicates that this favorable condition is not present: cost and risk are not significantly lower than those for comparable siting options.
(6) Availability of regional and local carriers--truck, rail, and water--which have the capability and are willing to handle waste shipments to the repository.	The evidence indicates that this favorable condition is present at Yucca Mountain: the Union Pacific Railroad is a regional carrier, local carriers will have the capability of supporting construction-related activities, and national or multiregional carriers will be deployed for waste shipments.

Table 6-12. Summary of analyses for Section 6.2.1.8; transportation (10 CFR 960.5-2-7) (continued)

Condition	Department of Energy (DOE) finding
<p>86-9</p> <p>FAVORABLE CONDITIONS (continued)</p>	
(7) Absence of legal impediment with regard to compliance with Federal regulations for the transportation of waste in or through the affected State and adjoining States.	The evidence indicates that this favorable condition is present at Yucca Mountain: existing State and local regulations considered to be impediments are preempted by Federal regulations, unless allowed to stand by the U.S. Department of Transportation, or the Federal judicial system.
(8) Plans, procedures, and capabilities for response to radioactive-waste transportation accidents in or through the affected State that are completed or being developed.	The evidence indicates that this favorable condition is present at Yucca Mountain: the State of Nevada and the DOE have plans, procedures, and capabilities for responding to accidents from transporting radioactive wastes.
(9) A regional meteorological history indicating that significant transportation disruptions would not be routine seasonal occurrences.	The evidence indicates that this favorable condition is present at Yucca Mountain: southern Nevada has one of the lowest frequencies of occurrence of severe weather in the United States, and significant transportation disruptions due to routine or seasonal severe weather conditions are not expected.
<p>POTENTIALLY ADVERSE CONDITIONS</p>	
(1) Access routes to existing local highways and railroads that are expensive to construct relative to comparable siting options.	The evidence indicates that this potentially adverse condition is present at Yucca Mountain: the length of the railroad spur and the bridge over Fortymile Wash cause the construction cost to be high relative to comparable siting options.

Table 6-12. Summary of analyses for Section 6.2.1.8; transportation (10 CFR 960.5-2-7) (continued)

Condition	Department of Energy (DOE) finding
<p>POTENTIALLY ADVERSE CONDITIONS (continued)</p>	
(2) Terrain between the site and existing local highways and railroads such that steep grades, sharp switchbacks, rivers, lakes, landslides, rockslides, or potential sources of hazard to incoming waste shipments will be encountered along access roads to the site.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: the terrain slopes gently on road and rail access so that no sharp curves or steep grades are required; no hazards to waste shipments have been identified. No surface water is present between the site and existing highways and railroads and areas of expected landslides or rockslides will be avoided.
(3) Existing local highways and railroads that could require significant reconstruction or upgrading to provide adequate routes to the regional and national transportation system.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: the railspur will provide direct access to the national railroad system; the access road will link the site to U.S. Highway 95, a regional highway, therefore no upgrading of local highways and railroads will be required.
(4) Any local condition that could cause the transportation-related costs, environmental impacts, or risk to public health and safety from waste transportation operations to be significantly greater than those projected for other comparable siting options.	The evidence does not support the conclusion that this potentially adverse condition is not present at Yucca Mountain: as presently configured the proposed rail spur will pass close to a U.S. Air Force bombing range which could possibly increase the risk compared to other siting options. Consequently, this potentially adverse condition is present at Yucca Mountain.

Table 6-12. Summary of analyses for Section 6.2.1.8; transportation (10 CFR 960.5-2-7) (continued)

Condition	Department of Energy (DOE) finding
QUALIFYING CONDITION	
<p>The site shall be located such that (1) the access routes constructed from existing local highways and railroads to the site (i) will not conflict irreconcilably with the previously designated use of any resource listed in 960.5-2-5(d)(2) and (3); (ii) can be designed and constructed using reasonably available technology; (iii) will not require transportation system components to meet performance standards more stringent than those specified in the applicable DOT and NRC regulations, nor require the development of new packaging containment technology; (iv) will allow transportation operations to be conducted without causing an unacceptable risk to the public or unacceptable environmental impacts; taking into account programmatic, technical, social, economic, and environmental factors; and (2) the requirements of Section 960.5-1(a)(2) can be met.</p>	<p>Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): Yucca Mountain has adequate year-round access to transportation routes whose use will not conflict irreconcilably with the previously designated land use or land dedication to resource preservation; all routes can be constructed with reasonably available technology without excessive cost; transportation-system components will not be required to meet standards greater than applicable DOT and NRC regulations; no unacceptable environmental radiological or nonradiological risk to the public or environment from transportation operations is expected.</p>

Assumptions, data uncertainties, and consistency

In order to ensure that all sites were evaluated in a consistent manner, a common set of criteria were developed by the U.S. Department of Energy (DOE). Where possible, the criteria were quantified (Appendix A). These criteria will be identified as required in the following sections to explain the positions taken.

Information on the costs and risk of transporting wastes to the Yucca Mountain site along highways and rail lines must be regarded as best estimates only in view of the preliminary nature of the transportation studies.

6.2.1.8.3 Favorable conditions

(1) Availability of access routes from local existing highways and railroads to the site which have any of the following characteristics:

(i) Such routes are relatively short and economical to construct as compared to access routes for other comparable siting options.

Evaluation

Highway access to the Yucca Mountain site would originate at U.S. Highway 95 approximately 1 kilometer (0.5 mile) west of the Town of Amargosa Valley and extend about 25 kilometers (16 miles) northward to the site. The proposed rail line would originate from the Union Pacific line at Dike Siding, 18 kilometers (11 miles) northeast of downtown Las Vegas, and would extend approximately 161 kilometers (100 miles) to the site. Access road costs are estimated at \$12.5 million (1984 dollars). Rail and bridge costs are estimated at \$151 million (1984 dollars). For the purpose of interpreting this favorable condition, the DOE established criteria of 16 kilometers (10 miles) and \$10 million as relatively short and economical.

Conclusion

Yucca Mountain does not possess this characteristic of the favorable condition.

(ii) Federal condemnation is not required to acquire rights-of-way for the access routes.

Evaluation

Except for Dike Siding, the proposed rail access route and the access road are located exclusively on Federal lands administered by the DOE, the U.S. Department of the Air Force, and public-domain lands under the jurisdiction of the Bureau of Land Management (sections 6.2.1.1 and 6.2.1.3).

Conclusion

Since neither the proposed rail nor road access routes cross any private land, Federal condemnation will not be required. Therefore this favorable characteristic is present at Yucca Mountain.

(iii) Cuts, fills, tunnels, or bridges are not required.

Evaluation

The terrain along the route for both road and rail is gently sloping. Preliminary design estimates indicate that no tunnels and only a minimum amount of excavation would be required. Some minor drainage structures and a new bridge spanning Fortymile Wash would be constructed. The construction of this bridge presents no engineering or construction difficulties.

Conclusion

The only significant surface feature to be encountered is Fortymile Wash. Because a bridge over Fortymile Wash would have to be built, the evidence indicates that this favorable characteristic is not present at Yucca Mountain.

(iv) Such routes are free of sharp curves or steep grades and are not likely to be affected by landslides or rockslides.

Evaluation

The railbed will be designed for maximum grades of 1 to 3 percent. Curves will be limited to approximately 2 degrees. The roadbed will be designed for a maximum grade of 3 percent and will be free of sharp curves. Landslides or rockslides along the rail and highway access routes are unlikely because the routes will be chosen to avoid locations with the potential for such events.

Conclusion

The terrain for the proposed rail and road access routes is gently sloping, no sharp curves are required, and no difficult design or engineering problems in ensuring surface stability are expected. Therefore, the evidence indicates that this favorable characteristic is present at Yucca Mountain.

(v) Such routes bypass local cities and towns.

Evaluation

According to preliminary design drawings, the proposed rail spur will bypass the towns of Cactus Springs and Indian Springs, as well as the facilities at Indian Springs Air Force Base. The rail line will originate 18 kilometers (11 miles) northeast of downtown Las Vegas. The proposed access road to the site will intersect U.S. Highway 95 approximately 1 kilometer (0.5 mile) west of the town of Amargosa Valley. For purposes of evaluating sites on the basis of this guideline, the DOE criteria for local cities and towns are the population values established in 10 CFR 960.5-2-1(c)2

(1984) at 1,000 people per square mile and the associated 10 CFR 960.2 (1984), which defines a highly populated area as any place of 2,500 or more persons. No population centers greater than the given DOE criteria are located along these proposed routes.

Conclusion

Information indicates that the rail and highway access routes to the Yucca Mountain site will bypass local cities and towns; furthermore no population centers (as defined above) exist along the access routes. Therefore, the evidence indicates that this favorable characteristic is present at Yucca Mountain.

Summary conclusion for favorable condition 1

Favorable condition 1 is present at Yucca Mountain. To have this favorable condition, only one of the characteristics need be present. As shown in the above discussions, three of the favorable characteristics are present for the Yucca Mountain site.

(2) Proximity to local highways and railroads that provide access to regional highways and railroads and are adequate to serve the repository without significant upgrading or reconstruction.

Evaluation

This favorable condition applies to local roads and rail lines from the outer end of the access routes to a point where upgrading is no longer required.

The new access road to be constructed southward from the site will provide direct access to U.S. Highway 95, a regional highway, and no local highways will be used for the repository. The railroad spur from Yucca Mountain to Dike Siding, 18 kilometers (11 miles) northeast of Las Vegas, will connect directly to the national rail network.

Conclusion

No upgrading or reconstruction of local highways or rail lines is required. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(3) Proximity to regional highways, mainline railroads, or inland waterways that provide access to the national transportation system.

Evaluation

This favorable condition applies to the distance between the outer end of the access routes and the closest regional highway and mainline railroad that would be used.

The access road to be constructed southward from the Yucca Mountain site will provide direct access to U.S. Highway 95, a regional highway providing

access to Interstate 15, Interstate 40, and Interstate 80, all of which are part of the national transportation system. The proposed rail spur will connect directly to the main Union Pacific line. This is a class A main line, which among other things means that it is part of the Strategic Rail Corridor Network and therefore is part of the national network.

Conclusion

The proposed highway and rail access routes constructed from the Yucca Mountain site will hook up directly to the regional and national transportation systems, respectively. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

- (4) Availability of a regional railroad system with a minimum number of interchange points at which train crew and equipment changes would be required.

Evaluation of equipment changes

According to an official of the Union Pacific Railroad (Nunn, 1983) the Union Pacific could interchange at Ogden, Utah, with the Southern Pacific Railroad. This may not be required, however, because of the areas served directly by Union Pacific: (1) San Francisco, California, which is served by the recently acquired Western Pacific line; (2) the eastern United States as far east as St. Louis, Missouri, Chicago, Illinois, and Memphis, Tennessee; (3) the Pacific Northwest; and (4) the Gulf ports in Texas and Louisiana. Locomotives almost always go straight through from Salt Lake City to at least Yermo, California (both of which are transfer points), and often on to Los Angeles.

Evaluation of crew changes

Crew-change locations along the Union Pacific line between Salt Lake City and Los Angeles are Salt Lake City and Milford, Utah; Las Vegas, Nevada; and Yermo and Los Angeles, California. The vast majority and possibly all waste destined for Yucca Mountain by rail will travel southbound and be diverted to the spur at Dike Siding before reaching Las Vegas. Therefore the only railroad crew change would be for waste being shipped in general commerce heading northbound from southern California.

The DOE criterion for this favorable condition is the number of interchange points within 200 kilometers (125 miles) of the site. Las Vegas is the only one that will become an interchange point for waste (if any) that is being shipped in general commerce from California.

Conclusion

The regional railroad system has one interchange point within 200 kilometers (125 miles) of the site, which is the minimum number of interchange points. Data for comparison with other siting options can be found in Chapter 7. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(5) Total projected life-cycle cost and risk for transportation of all wastes designated for the repository site which are significantly lower than those for comparable siting options, considering locations of present and potential sources of waste, interim storage facilities, and other repositories.

Evaluation

Projected life-cycle cost and risk for the transportation of all wastes designated for the potential repository at Yucca Mountain are presented in Section 5.3 and Appendix A. The data for cost and risk for comparable siting options can be found in Chapter 7. The long distance involved in travel from the east produces relatively high shipping cost and risk for the Yucca Mountain site.

Conclusion

As cost and risk are strongly influenced by distance, the evidence suggests that this favorable condition is not present for Yucca Mountain.

(6) Availability of regional and local carriers--truck, rail, and water--which have the capability and are willing to handle waste shipments to the repository.

Evaluation

The analysis in Section 5.3 indicates that the Union Pacific Railroad has the capacity to carry the shipments associated with waste transport. Waste transport by truck will be contracted for on a national or multi-regional basis, thereby taking the burden off of local carriers.

Conclusion

The Union Pacific meets the qualifications of a regional carrier having the capacity to handle waste shipments as noted in Section 5.3. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(7) Absence of legal impediment with regard to compliance with Federal regulations for the transportation of waste in or through the affected State and adjoining States.

Evaluation

A legal impediment could only exist if State, local, or tribal law rendered compliance with U.S. Department of Transportation (DOT) regulations impossible, without being found to be preempted by the Federal judicial system. California time-of-day requirements and the banning of radioactive waste shipments in Humboldt and Marin counties as well as the recently passed Las Vegas, Nevada, ordinance (No. 3190), are the only regulations considered impediments to waste shipments. However, these regulations are considered preempted by DOT regulations until they are allowed to stand by either DOT or the Federal judicial system.

Conclusion

There are no legal impediments that are not considered to be preempted by DOT regulations. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(8) Plans, procedures, and capabilities for response to radioactive waste transportation accidents in the affected State that are completed or being developed.

Evaluation

The State of Nevada Radiological Emergency Response Plan (State of Nevada, Department of Human Resources, 1983) identifies the agencies and individuals to be notified in the event of a radiological emergency, provides guidance for plan participants, and establishes procedures for requesting and providing assistance.

Through an agreement with Region 7 of the DOE, and in accordance with the Memorandum of Understanding on responses to hazardous materials accidents, the DOE Nevada Operations Office (DOE/NVO) is the primary contact for coordination of the initial response to a radiological emergency in the State of Nevada. Telephone calls are answered by the 24-hour guard station at the main DOE office building in Las Vegas. Cards containing this number have been distributed by the Nevada State Division of Emergency Management to State, county, and city authorities. Duty officers assigned on a rotating schedule ensure immediate 24-hour contact with the DOE guard station using a beeper and can be immediately mobilized when needed. Notification procedures of the Radiological Assistance Team are published by the DOE/NVO (1985). In southern Nevada, a Radiological Assistance Team with a specially equipped vehicle is also available. In northern Nevada, the State Emergency Response Team, composed of State and university personnel, is responsible for emergency response.

The capability of the DOE for responding to radiological emergencies is well developed in terms of trained personnel, equipment, and facilities. Professional personnel--including health physicists, medical specialists, physical and biological scientists, and technical personnel such as radiation monitors, instrumentation specialists, and radioactive-material handlers--are included in the Radiological Assistance Team. In addition, the team is accompanied by a trained public-affairs person. Equipment is available for personnel protection, transportation, communications, and radiation monitoring; facilities are also available for biological assays, chemical analyses, and decontamination. Regional capability includes, in addition to the Radiological Response Cleanup Team, an Aerial Measurements Systems Group that has the ability to rapidly assess very large land areas.

First-on-scene training courses have been developed and conducted for ambulance operators and Nevada State law-enforcement personnel. Civil defense radiation-monitoring kits have been given to each State highway patrolman and selected municipal and county officers who complete the training course. The kits are maintained regularly.

The DOE criterion for this favorable condition is that evidence exists that there are plans, procedures, and capabilities.

Conclusion

The State of Nevada in cooperation with the DOE Nevada Operations Office has completed plans, procedures, and capabilities for responding to accidents during the transportation of radioactive materials. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

- (9) A regional meteorological history indicating that significant transportation disruptions would not be routine seasonal occurrences.

Evaluation

Recorded occurrences of severe weather in Nevada include thunderstorms, snowstorms, tornadoes, hail, and sandstorms, but the frequencies of most events are very low. Thunderstorms have been observed on the average of 14 days per year at Yucca Flat (Bowen and Egami, 1983), 11 days per year at Winnemucca to the north, 14 days per year at Reno to the northwest, and 31 days per year at Ely, to the northwest (DOC, 1952). Approximately 60 to 70 percent of these thunderstorms occur during the summer season. Tornadoes are very rare in Nevada, with the probability of a tornado striking Yucca Mountain conservatively estimated to be 7.5×10^{-4} per year, or once in 1,333 years (Thom, 1963). Occurrences of tornadoes elsewhere in the State are equally rare, and no tornado-related deaths have been reported for Nevada for the record period from 1916 to 1953 (Lineham, 1957). Hail with a diameter of 1.9 centimeters (0.75 inch) or larger was observed on 7 days in Nevada between 1955 and 1967 (Pautz, 1969). Sandstorms are common in Nevada, but they are rarely severe enough to affect transportation. The greatest 24-hour snowfall measured at Yucca Flat was 21 centimeters (8.3 inches) (Bowen and Egami, 1983). Annual total snowfalls of up to 150 centimeters (60 inches) have been observed at some of the higher elevations in the State (DOC, 1968), but these areas are not likely to be traversed by waste-transportation carriers. The annual precipitation in Nevada is generally low, with the northern half of the State receiving more precipitation than the arid southern region.

Although it is not strictly a weather condition, but rather the result of regional sporadic weather conditions, the possibility of flash flooding will be taken into account in the design of access routes. Beatty rainfall patterns should be indicative of the southwestern Nevada Test Site. A 24-hour precipitation event of more than 51 millimeters (2.0 inches) has a recurrence period of 25 years for Beatty (Bowen and Egami, 1983). At Yucca Flat, the statistical maximum 24-hour precipitation for 10- and 100-year storm events is 38 and 57 millimeters (1.50 and 2.25 inches), respectively (Hershfield, 1961). Quiring (1983) updated the 10- and 100- year storm event precipitation data for Yucca Flat to 45 and 68 millimeters (1.8 and 2.7 inches) respectively. Flash floods resulting from this intense rainfall are generally of short duration, and standard drainage-control measures should reduce risks to acceptable levels.

The above data suggest that significant transportation disruptions due to weather are rare in Nevada. This is supported by road-closure information obtained from Hill (1985a,b), which states that

1. During 1984 there were three total closures of Interstate 15 and no total closures of Interstate 80 due to weather conditions.
2. Over the past year U.S. Highway 95 between Interstate 15 and Interstate 80 was closed three times because of weather.
3. All total closures were due to flooding.

The DOE criterion defines significant disruptions as those that could cause the repository not to meet its annual receipt rate.

Conclusion

Southern Nevada has one of the lowest frequencies of occurrence of severe weather in the United States. Road-closure information suggests that transportation disruptions would not be routine seasonal occurrences and would not adversely affect the ability of the repository to meet its annual receipt rate. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

6.2.1.8.4 Potentially adverse conditions

- (1) Access routes to existing local highways and railroads that are expensive to construct relative to comparable siting options.

Evaluation

Details of access routes for the Yucca Mountain site are presented in the evaluation of favorable condition 1(i). As with favorable condition 1(i), the U.S. Department of Energy (DOE) criterion for expensive construction was set equal to or greater than \$10 million.

Conclusion

According to the DOE criterion, Yucca Mountain possesses this potentially adverse condition.

- (2) Terrain between the site and existing local highways and railroads such that steep grades, sharp switchbacks, rivers, lakes, landslides, rock slides, or potential sources of hazard to incoming waste shipments will be encountered along access roads to the site.

Evaluation

The terrain along the road and rail access routes is gently sloping, and steep grades, sharp switchbacks, rivers, lakes, landslides, rock slides, or other potential sources of hazard to incoming waste shipments will not be encountered along access routes to the proposed site (see favorable conditions 1(iii) and (iv)).

Conclusion

The access road and rail spur will be built over terrain that presents no potential hazards to incoming waste shipments. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

- (3) Existing local highways and railroads that could require significant reconstruction or upgrading to provide adequate routes to the regional and national transportation system.

Evaluation

The proposed rail spur from the site to Dike Siding will provide direct access to the national railroad system. Hence, there will be no upgrading or reconstruction of existing local networks. The access road will provide access directly to the regional network (U.S. Highway 95). Consequently, no upgrading of local roads will be required (see favorable condition 2).

Conclusion

There are no local highways and railroads connecting the Yucca Mountain site to the regional or national transportation system. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

- (4) Any local condition that could cause the transportation-related costs, environmental impacts, or risk to public health and safety from waste transportation operations to be significantly greater than those projected for other comparable siting options.

Evaluation

Risk to public health and safety from transportation operations for comparable siting options is addressed in Chapter 7 and in Appendix A. These conditions are evaluated for only the Yucca Mountain site. The population density in the area covered by access routes to the potential Yucca Mountain site for rail and highway is very low, as discussed in the preclosure system guideline for radiological safety (Section 6.2.2.1). There are no permanent residents within 10 kilometers (6.2 miles) of the site. The costs are not expected to be unreasonable for constructing either route, because the terrain is generally flat or gently sloping, no tunnels need to be excavated, and only one bridge is required. No specialized technology is required for constructing the rail line or highway. Much of the land is already controlled by the Federal Government. Environmental impacts from access road and rail construction and use are expected to be minimal. However, the rail spur as currently envisioned will pass close to a U.S. Air Force (USAF) bombing ranges in the vicinity of Indian Springs. Although there is no evidence to suggest that this presents a significantly greater risk than other comparable siting options, a detailed study will be conducted during site characterization to examine the potential risk associated with the relative location of the proposed rail spur and military activities in the area.

Conclusion

Since the risk associated with the proximity of the rail spur to the USAF bombing ranges has yet to be quantified, it cannot be concluded that Yucca Mountain does not possess this potentially adverse condition. Consequently, the evidence indicates that this potentially adverse condition is present at Yucca Mountain.

6.2.1.8.5 Evaluation and conclusion for the qualifying condition on the transportation guideline

Evaluation

Except for Dike Siding, all the rail and highway access routes for the Yucca Mountain site are located on government controlled lands, and no Federal condemnation proceedings are expected. Access routes constructed from existing highways and railroads will not conflict irreconcilably with the previously designated use of any environmental resource listed in Section 6.2.1.6 (Environmental quality). These routes can be constructed with reasonably available technology. Transportation-system components can be designed to meet applicable Department of Transportation and Nuclear Regulatory Commission regulations.

Construction costs for access routes, although high compared with other sites, should not be unreasonable, because the terrain is generally flat or gently sloping, no tunnels would need to be excavated, and only one bridge would be required. The existing roads and railroads provide ready access to the regional transportation system without requiring upgrading of local roads. Also, the Union Pacific Railroad serves many distant points, minimizing the need for equipment and crew changes. Because southern Nevada has one of the lowest frequencies of severe weather in the United States, transportation would not be adversely affected by weather conditions.

The public and the environment can be adequately protected from any potential hazards posed by the transportation of radioactive wastes (Section 6.2.2.2). No local conditions have been identified that would make the risk to public health and safety unacceptable. The State of Nevada in cooperation with the U.S. Department of Energy (DOE) has completed plans and procedures for responding to accidents involving radioactive materials. The DOE Nevada Operations Office coordinates the response to radiological emergencies.

Conclusion

The Yucca Mountain site has adequate access to existing transportation routes, and new access routes can be constructed with reasonably available technology and at reasonable cost. Transportation operations can be conducted without causing unacceptable radiological or nonradiological risk to the public or unacceptable environmental impacts. Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition for transportation (level 3).

6.2.2 PRECLOSURE SYSTEM GUIDELINES

The purpose of the preclosure system guidelines is to establish the overall objectives to be met by a repository during the preclosure phase (i.e., siting, construction, and operation through closure). There are three preclosure system guidelines: (1) preclosure radiological safety; (2) environment, socioeconomic, and transportation; and (3) ease and cost of siting, construction, operation, and closure. The first two are discussed in this section; the third, which addresses the four preclosure guidelines that require data from site characterization, is discussed in Section 6.3.2.

6.2.2.1 Preclosure system guideline: radiological safety (10 CFR 960.5-1(a)(1))

6.2.2.1.1 Introduction

The qualifying condition for this guideline is as follows:

Any projected radiological exposures of the general public and any projected releases of radioactive materials to restricted and unrestricted areas during repository operation and closure shall meet the applicable safety requirements set forth in 10 CFR Part 20, 10 CFR Part 60, and 40 CFR 191, Subpart A.

The system guideline on preclosure radiological safety is assigned the greatest importance among the preclosure guidelines because it is directed at protecting both the public and the workers at the repository from radiological exposures, as required by the performance objective of 10 CFR Part 60 (1983) for radiological safety. During the preclosure phase, this objective is achieved mainly through engineering technology (e.g., high-integrity structures, air-treatment systems, radiation monitors) and Nuclear Regulatory Commission (NRC)-approved operating procedures.

The system elements that must be considered in evaluations for this guideline are (1) the site characteristics that affect radionuclide transport through the surroundings; (2) the engineered components with the function to control releases of radioactive materials; and (3) the people who, because of their location and distribution in unrestricted areas, may be affected by radionuclide releases. Although details about its engineered components are not yet available, the repository will have to comply with the regulatory release limits. This compliance will have to be demonstrated to the satisfaction of the NRC, which will review both the engineering designs and operating procedures. Among the features that will contribute to operational safety will be the waste form (solid) and the waste package that will contain the radioactive materials and prevent their dispersal; high-efficiency air filters that will control airborne radioactive emissions into the atmosphere; and water-purification systems, which will be used to decontaminate any water used for the cleanup of facilities or components. Table 6-13 summarizes the finding for the qualifying condition. The remainder of this section summarizes the data available, presents an evaluation, and draws a conclusion.

Table 6-13. Summary of analyses for Section 6.2.2.1; preclosure system guideline: radiological safety (10 CFR 960.5-1(a)(1))

Condition	Department of Energy (DOE) finding
QUALIFYING CONDITION	
Any projected radiological exposures of the general public and any projected releases of radioactive materials to restricted and unrestricted areas during repository operation and closure shall meet the applicable safety requirements set forth in 10 Part 20, 10 CFR Part 60, and 40 CFR 191, Subpart A.	Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): preferential radionuclide transport to population centers is not expected; the site is in an area of low population density; the DOE will gain the necessary land ownership and control through interagency transfers; severe weather is infrequent and normally of short duration; and engineered components are expected to contain waste and retard radionuclide migration so that all applicable safety requirements are met.

6.2.2.1.2 Data relevant to the evaluation

Supporting data and information about the engineered components that will control releases of radioactive materials at the Yucca Mountain site are summarized in a preliminary safety assessment (Jackson et al., 1984). The safety assessment provides estimates of upper limits to potential doses from accidents at the repository; all the first-year estimated doses are total-body doses, derived by considering the body as a mass of undifferentiated tissue, rather than whole-body doses which are derived by weighting the doses to each affected organ and summing to produce an integrated dose to the body (Jackson et al., 1984). Population data for Nye and Clark counties were obtained from reports by the Clark County Department of Comprehensive Planning (1983) and Smith and Coogan (1984), respectively. Meteorologic data compiled by Bowen and Egami (1983), Holzworth (1972), and Quiring (1968, 1965) have been used to evaluate the potential for airborne radionuclide transport and dispersion. Studies by Winograd and Thordarson (1975) and Montazer and Wilson (1984) were used to evaluate the hydrogeology of Yucca Mountain. For relevant data supporting the technical guidelines that are used to provide a preliminary assessment of this system guideline, see the corresponding relevant data compilations.

In support of the evaluation made in this section, the preclosure performance of the repository is evaluated in Section 6.4.1, which presents a radiological safety assessment and the applicable radiation-protection standards from 10 CFR Part 20 (1984), 10 CFR Part 60 (1983), and 40 CFR 191, Subpart A (1985). This preliminary assessment, based on generic studies of repository operations, predicts the releases of radionuclides that may occur during normal operation of the repository.

6.2.2.1.3 Evaluation of the Yucca Mountain site

Those technical guidelines that contribute to the evaluation of this system guideline include population density and distribution (Section 6.2.1.2), site ownership and control (sections 6.2.1.1 and 6.2.1.3), meteorology (Section 6.2.1.4), and offsite installations and operations (Section 6.2.1.5). Evaluations of favorable and potentially adverse conditions in these technical guidelines are used as preliminary system-performance indicators that can be applied before site characterization.

The objective of the guideline on population density and distribution is to ensure that the site will meet the Environmental Protection Agency (EPA) and the Nuclear Regulatory Commission (NRC) regulations with minimum risk to the public. The area around the site is one of the most sparsely populated regions in the contiguous 48 states. Present site ownership and control provide the basis for limiting the entry of people onto the site during operation and closure. The eastern portion of the site is on the Nevada Test Site (NTS), which is controlled by the U.S. Department of Energy (DOE); the northwestern portion of the site is on the Nellis Air Force Range (NAFR), which is controlled by the Department of the Air Force; and the southwestern portion of the site is held in public trust by the Bureau of Land Management. It is expected that the DOE can acquire jurisdiction and control over the remaining portions of the land, including surface and subsurface rights.

There are no permanent residents within 10 kilometers (6 miles) of the site and all land within this radius is currently federally controlled and not open to settlement. Access to the NAFR and NTS is restricted. Nye County, where the Yucca Mountain site is located, had a 1980 population density of 0.5 person per square mile (Table 3-26). The nearest population center is located in the unincorporated Town of Amargosa Valley, whose residents are spread out in numerous small settlements within its estimated 1,036 square kilometers (400 square miles) (Section 3.6.4.1.1). Major population concentrations are located in the community formerly called Lathrop Wells, and now also called Amargosa Valley, approximately 23 kilometers (14 miles) to the south; the Amargosa Farm Area, approximately 37 kilometers (23 miles) to the south and the American Borate housing complex, roughly 45 kilometers (28 miles) to the south. Population of these areas in 1984 was estimated to be 45, 1500, and 280 respectively (Smith and Coogan, 1984). An estimate of the total population of the unincorporated Town of Amargosa Valley is not available.

Beatty, located about 31 kilometers (19 miles) to the northwest had an 1984 estimated population of 800 (Smith and Coogan, 1984). Pahrump's 1984 population was estimated to 5,500 (Smith and Coogan, 1984). It is located slightly more than 80 kilometers (50 miles) to the southeast. The nearest highly populated area is in the Las Vegas Valley area about 137 kilometers (85 miles) by air southeast of Yucca Mountain. This is also the nearest 1 mile by 1 mile area having a population of at least 1,000 individuals (Clark County Department of Comprehensive Planning, 1983). All of the distances cited above are straight-line distances, not road distances.

Calculations for worst-case accident scenarios at Yucca Mountain have been completed. Preliminary results of a safety assessment study are available (Jackson et al., 1984). This study assumes that a person could be temporarily in an area 4 kilometers (2.5 miles) from the surface facilities. Assuming this person to be the maximally exposed individual, preliminary calculations for an extremely severe and unlikely accident at the repository estimate that the worst-case maximum individual total-body equivalent dose would be 0.055 rem, (0.068 rem 50-year dose commitment). For comparison, the limit specified in 10 CFR Part 20 (1984) for normal operations is 0.5 rem per year for an individual in an unrestricted area. The worst-case accident-related radiation exposure of the 19,908 people conservatively assumed, for purposes of estimating worst-case dose, to live within 80 kilometers (50 miles) of the repository site at Yucca Mountain, is 110 man-rem, which is much less than the annual background-radiation external dose commitment of about 1,790 man-rem to the same number of people.

Radionuclides released to the environment can potentially be transported by both liquid and gaseous transport mechanisms. At the Yucca Mountain site, surface-water transport mechanisms are not considered likely, because of the aridity of the climate and the absence of surface water. The Yucca Mountain site is located in one of the most arid regions of the United States, with an average annual rainfall in the region of less than 150 millimeters (6 inches) (Quiring, 1965; Bowen and Egami, 1983). The arid conditions allow very limited infiltration and recharge (Winograd and Thordarson, 1975; Montazer and Wilson, 1984). Ground-water transport is not a reasonable release mechanism during the operation of the repository owing to the long ground-water travel time that is expected in the unsaturated zone (Section 6.3.1.1.5).

The potential for retardation of radionuclides in the zeolitized tuffaceous beds of the Calico Hills beneath the repository, and the great distance between the site and a down-gradient population center where ground water is withdrawn are also favorable conditions in this regard. The air pathway may therefore represent the most likely pathway of radionuclide travel during the period when gaseous radionuclides are present in the radioactive waste.

Table 6-46 in Section 6.4.1 provides estimates of expected radionuclide releases under normal repository operation for a generic repository. The maximum releases predicted were for krypton-85 and would result in an air concentration of 6.3×10^{-8} curie per cubic meter at the point of discharge. The concentration limit for krypton-85 from 10 CFR Part 20 (1984) is 3×10^{-7} curie per cubic meter. Dispersion between the discharge point and the site boundary is likely to further reduce the krypton-85 concentration. Other concentration estimates for tritium, carbon-14, and iodine-129 would also be below the limit from 10 CFR Part 20. The estimated annual dose equivalent for immersion in the dispersed cloud of airborne radionuclides listed in Table 6-46 is predicted to be less than 1.0 millirem per year (Section 6.4.1), which represents only about 1 percent of the dose received from natural background by an individual in the vicinity of the NTS.

Meteorological data from Yucca Flat (40 kilometers (25 miles)) east of Yucca Mountain) have been used to suggest that the site is well ventilated. Isopleths of mean annual mixing heights show that the region experiences some of the deepest atmospheric mixing in the United States (Holzworth, 1972). Surface winds are not likely to cause preferential transport toward regional population centers. Upper-air data from Yucca Flat for 1,500 and 1,800 meters (5,000 and 6,000 feet) above mean sea level (Quiring, 1968), which is beyond the influence of local terrain, show that wind from the northwest toward Las Vegas occurred only 11 percent of the time on an annual basis. Winds from the east, which would transport material toward Beatty, occurred only 2 percent of the time. Winds from the north, which would transport material toward the Town of Amargosa Valley, occurred approximately 20 percent of the time.

The 10-year record of wind speeds shows that the average wind velocity at Yucca Flat is high, 11.9 kilometers (7.4 miles) per hour (Bowen and Egami, 1983). Extreme weather phenomena are not likely to cause disruptions in repository operation or closure activities because southern Nevada has one of the lowest frequencies of severe weather in the United States, and the extreme events are generally of very short duration.

Site-specific meteorological data are insufficient to predict local wind directions at Yucca Mountain. These data will be collected by weather stations recently installed at Yucca Mountain. Data obtained over the next several years from new weather towers will be used to refine the radionuclide dispersion calculations that are currently based on data from Yucca Flat and to verify that Yucca Mountain conditions have been accurately predicted. As they are developed during the design process, details of the engineered components of the repository will be examined to determine whether the preliminary information used in evaluating the site against the technical guidelines was correct and to perform rigorous analyses of operational safety.

The impacts of nearby atomic energy defense activities that take place on the NAFR and the NTS are discussed under the guideline on offsite installations and operations. Airborne radionuclides from the NTS detected off the site from 1974 through 1983 are listed in Table 6-7. There were no detectable offsite radionuclide releases from nuclear weapons tests at the NTS during 4 out of 5 of the most recent 1-year monitoring periods. These releases are not regulated by 40 CFR Part 191 (1985).

6.2.2.1.4 Conclusion for the qualifying condition on the preclosure system guideline: radiological safety

A preliminary evaluation of the system elements pertinent to the system guideline on preclosure radiological safety shows that the characteristics of the site favor its ability to limit exposure to radiation among workers and the public; the distribution of people who live outside the area would also restrict exposures. Estimates of both the extreme worst-case accidental radiological exposures to the general public and the exposures due to normal operation are below the limits specified in 10 CFR Part 20 (1984), 10 CFR Part 60 (1983), and 40 CFR 191, Subpart A (1985). Estimated releases under normal repository operation (Section 6.4.1) produce radionuclide concentrations that are well below the maximum permissible concentrations. The evidence does not support a finding that the site is not likely to meet the qualifying condition for this preclosure system guideline (level 3).

6.2.2.2 Preclosure system guideline: environment, socioeconomics, and transportation (10 CFR 960.5-1(a)(2))

6.2.2.2.1 Introduction

The qualifying condition for this guideline is as follows:

During repository siting, construction, operation, closure, and decommissioning the public and the environment shall be adequately protected from the hazards posed by the disposal of radioactive waste.

The preclosure system elements for this guideline include (1) the interaction between repository-related activities and the existing economic, social, and demographic conditions of the area; (2) the air, land, water, plants, animals, and cultural resources in the areas potentially affected by repository activities; (3) the transportation infrastructure; and (4) the potential mitigation and compensation measures that can be used to offset adverse impacts. Table 6-14 summarizes the findings for the qualifying condition.

Table 6-14. Summary of analyses for Section 6.2.2.2; preclosure system guideline: environment, socioeconomics and transportation (10 CFR 960.5-1(a)(2))

Condition	Department of Energy (DOE) finding
QUALIFYING CONDITION	
During repository siting, construction, operation, closure, and decommissioning the public and the environment shall be adequately protected from the hazards posed by the disposal of radioactive waste.	Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): there are no significant environmental impacts that cannot be mitigated; the socioeconomic welfare of the public can be preserved; transport of wastes can be conducted in compliance with regulations; the public and the environment will be adequately protected from the hazards posed by radioactive waste disposal.

6.2.2.2.2 Data relevant to the evaluation

The data used to evaluate the potential environmental impacts of the repository consist of (1) surveys and published reports on the biologic, archaeologic, and hydrologic conditions of the Yucca Mountain area (see Chapter 3); (2) analyses in Chapter 4 on the environmental consequences of site characterization; and (3) analyses in Chapter 5 on the near- and long-term environmental consequences of constructing, operating, closing, and decommissioning a nuclear waste repository at Yucca Mountain. Chapters 4 and 5 also present an evaluation of potential transportation impacts and preliminary evaluations of the socioeconomic impacts of site characterization and repository construction and operation at Yucca Mountain.

6.2.2.2.3 Evaluation of the Yucca Mountain site

The evaluation of the Yucca Mountain site against this system guideline is based on the evaluations reported for the technical guidelines for environmental quality (Section 6.2.1.6), socioeconomic impacts (Section 6.2.1.7), and transportation (Section 6.2.1.8).

As discussed in chapters 4 and 5, the potentially significant adverse environmental impacts associated with siting, constructing, operating, closing, and decommissioning a repository at Yucca Mountain include (1) destruction of approximately 680 hectares (1,608 acres) of desert habitat; (2) fugitive-dust emissions from surface preparation, excavation, and manipulation of spoils piles; (3) vehicle emissions from waste transport, personnel transport, materials transport, and operation of construction equipment; and (4) radioactive-material releases during (a) repository excavation (from naturally occurring radon and decay products in volcanic rocks), (b) normal operation of the repository, and (c) accidents. Potential impacts on surface and ground water are considered insignificant, chiefly because there is no perennial surface water in the area, and ground water is several hundred meters beneath the repository horizon (Section 6.3.1.1). A permanent land withdrawal will be required if the Yucca Mountain site is selected for repository development, and the reservation of water rights is explicit in such an action. Studies to date suggest that aquifers underlying the proposed surface facility locations can produce large quantities of water for long time periods without lowering the regional ground-water table. Other potential impacts, such as the diversion of natural runoff and the leaching of materials from excavated rock, are being considered in the repository design, and they are not expected to pose significant environmental problems.

During repository construction, the maximum estimated ambient concentrations of particulates, carbon monoxide, and the oxides of sulfur and nitrogen are not expected to exceed the air-quality limits of 40 CFR Part 50 (1983). Assuming the project is subject to the Prevention of Significant Deterioration provisions of the Clean Air Act Amendments of 1977, the predicted pollutant concentrations would violate none of the applicable standards.

The evaluations of the socioeconomic impacts guideline in Section 6.2.1.7 are briefly summarized below.

Negative impacts on community services, housing supply and demand, and the finances of State and local government agencies in the affected area are

not expected to be significant for repository siting, construction, operation, and decommissioning.

The maximum 1-year percent increase in the bicoounty population would occur during the second year of construction (1994). The maximum 1-year percent increase is estimated to be 4.0 percent for Nye County and 3.7 percent for Clark County. The affected (bicoounty) area, including the Las Vegas Valley, has the ability to absorb the repository-related population changes without significant disruptions of community services and without significant impacts on housing supply and demand.

Although community-specific service and housing demands could increase at rates proportional to the maximum 1-year community population growth rates estimated with the repository, these rates are generally within the range of those experienced historically by the urban communities (approximately 2.7 to 13.2 percent) and their municipal service providers. Because the unincorporated towns nearest the Yucca Mountain site have limited powers dealing with community services, potential population growth in these communities would generally impact county-wide service providers. These service providers are more likely to have resources for managing growth. Additionally, the community level growth rates estimated for the unincorporated towns are generally within range of those experienced historically by Nye and Clark counties (tables 3-15 and 3-16). Ample land is available for housing in the rural communities closest to the Yucca Mountain site.

The primary sectors of the economy in southern Nevada are tourism and mining. The employment impacts of site characterization on these sectors are expected to be insignificant. Information available to date does not suggest that repository construction and operation would significantly affect tourism. Construction and operation of a repository would significantly increase employment in mining and moderately increase employment in construction. These employment increases are not considered to represent major disruptions of these sectors.

The work force in southern Nevada, including the Las Vegas Valley, is sufficiently large to site, construct, and operate a repository at Yucca Mountain. Although an adequate total work force may be available for a repository at Yucca Mountain, the available work force with mining skills would be inadequate and it is possible that the available construction work force may also be inadequate.

A repository at Yucca Mountain would increase employment and business sales in southern Nevada. Community services and government revenues are likely to increase.

In summary, preliminary analyses of labor demand, materials and resources, income, and land use reveal no potentially significant adverse impacts. It is expected that impacts on State and local community infrastructure discussed in Section 5.4 can be offset by reasonable mitigation or compensation under the financial and technical assistance provisions of the Nuclear Waste Policy Act (NWPA, 1983). The U.S. Department of Energy (DOE) maintains a commitment to consult and cooperate with responsible State and local governments in identifying specific areas where adverse impacts could

occur and in developing appropriate measures of corrective action and mitigation.

For rail access to Yucca Mountain, a rail line extending approximately 161 kilometers (100 miles) from existing mainline rail facilities at Dike Siding (northeast of Las Vegas) has been proposed (see Figure 5-2). This route would be entirely on government-controlled lands administered by the DOE and the U.S. Department of the Air Force, as well as public-domain lands under the jurisdiction of the Bureau of Land Management.

The terrain over which the rail line would cross is gently sloping. No tunnels and only a minor amount of excavation and fill would be required. A bridge would be required at Fortymile Wash several miles east of Yucca Mountain. The construction of the proposed rail line from the site to Dike Siding would provide direct access to the national railroad system.

For highway access to the proposed site, a route is projected northward from U.S. Highway 95, originating approximately 1 kilometer (0.5 mile) west of the intersection of U.S. Highway 95 and Nevada State Route 373. U.S. Highway 95 is a regional highway providing access to the Interstates 15, 40, and 80, which are all part of the national transportation system. The roadway access would be constructed on federally controlled lands that slope gently and would pose no significant engineering problems. No tunnels and only a minor amount of excavation would be required. Some minor drainage control measures and a bridge spanning Fortymile Wash would be required. The bridge would be a common carrier for both rail and truck access. U.S. Highway 95 between Las Vegas and Mercury is a four-lane divided highway; it is a two-lane highway from Mercury to the access road near intersection of U.S. Highway 95 and Nevada State Route 373. A requirement for significant upgrading of this regional highway is unlikely.

A legal impediment could only exist if State, local, or tribal law rendered compliance with U.S. Department of Transportation (DOT) regulations impossible, without being found preempted by the (DOT) or the Federal judicial system. California time-of-day requirements and the banning of radioactive waste shipments in Humboldt and Marin counties as well as the recently passed Las Vegas, Nevada, ordinance (No. 3190) are the only regulations that could be considered an impediment to waste shipments. However, these regulations are considered preempted by DOT regulations until they are allowed to stand by either the DOT or the Federal judicial system.

6.2.2.2.4 Conclusion for the qualifying condition on the preclosure system guideline: environment, socioeconomics and transportation

The repository and its support facilities could be sited, constructed, operated, closed, and decommissioned at Yucca Mountain while protecting the public and the environment from the hazards posed by disposal of radioactive waste. Furthermore, measures to offset, mitigate, or compensate projected environmental impacts and significant adverse social and economic impacts exist or are expected to be developed through a process of analysis, planning, and consultation among the DOE, affected State, and local government jurisdictions. Efforts will be made to preserve the socioeconomic welfare of

the general public in the affected area and to protect the socioeconomic welfare and the aesthetic values of the region. The projected risks, costs, and other impacts of waste transportation are being considered in the evaluation of the Yucca Mountain site, and there is no evidence to suggest that transportation of wastes cannot be conducted in compliance with applicable Federal regulations, and with State and local regulations that are applicable and consistent with these Federal regulations. Analyses of worst-case operational and nonoperational accidents at a potential repository at Yucca Mountain indicate that population exposures would be small compared to natural background sources. The evidence does not support a finding that the site is not likely to meet the qualifying condition of this preclosure system guideline (level 3).

6.2.3 CONCLUSION REGARDING SUITABILITY OF THE YUCCA MOUNTAIN SITE FOR DEVELOPMENT AS A REPOSITORY

On the basis of the findings stated in the previous discussion of individual guidelines and made in accordance with Appendix III of the siting guidelines (10 CFR Part 960, 1984), it is concluded that the evidence does not support a finding that the site is disqualified and does not support a finding that the site is not likely to meet the qualifying conditions. Therefore, it is concluded on the basis of those guidelines that do not require data and information from site characterization that there is no reason to believe that the Yucca Mountain site is not suitable for development as a repository.

6.3 SUITABILITY OF THE YUCCA MOUNTAIN SITE FOR SITE CHARACTERIZATION: EVALUATION AGAINST THE GUIDELINES THAT DO REQUIRE SITE CHARACTERIZATION

This section presents preliminary evaluations of the Yucca Mountain site against the twelve technical and the two system guidelines that require data from site characterization for a determination of compliance. The post-closure guidelines are discussed first, in sections 6.3.1 (technical guidelines) and 6.3.2 (system guidelines). The preclosure guidelines are covered in sections 6.3.3 (technical guidelines) and 6.3.4 (system guidelines).

6.3.1 POSTCLOSURE TECHNICAL GUIDELINES (10 CFR 960.4-2)

The postclosure technical guidelines address the site conditions that are related to the long-term performance of the repository. They address geohydrology, geochemistry, rock characteristics, climatic changes, erosion, dissolution, tectonics, and human interference. For each technical guideline, an introduction describes the objective of the guideline and refers to a table that states the entire guideline and summarizes the evaluations. After a description of the relevant data, a series of evaluations show whether the Yucca Mountain site is likely to possess the favorable,

potentially adverse, disqualifying, and qualifying condition(s) that are included in the guideline.

6.3.1.1 Geohydrology (10 CFR 960.4-2-1)

6.3.1.1.1 Introduction

The qualifying condition for this guideline is as follows:

The present and expected geohydrologic setting of a site shall be compatible with waste containment and isolation. The geohydrologic setting, considering the characteristics of and the processes operating within the geologic setting, shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered barrier system using reasonably available technology.

The geohydrology guideline addresses the present and expected characteristics of the geohydrologic setting of the site and processes operating within this geohydrologic setting; it requires that these characteristics and processes be compatible with waste containment and isolation. After repository closure, the most likely mechanism for the release of radionuclides from a repository to the accessible environment is transport by ground water. To evaluate this potential for release in the postclosure time period, it is necessary to characterize the volume, flow paths, velocities, and travel times for ground water.

This guideline consists of five favorable conditions, three potentially adverse conditions, one disqualifying condition, and one qualifying condition. The evaluations reported below are summarized in Table 6-15 for all conditions except the disqualifying condition.

6.3.1.1.2 Data relevant to the evaluation

Summary of available data

Because a repository at Yucca Mountain would be above the water table, discussions about radionuclide movement must consider unsaturated rocks as well as saturated rocks. The geohydrologic system at Yucca Mountain is composed of a thick (about 300 to 750 meters (1,000 to 2,500 feet)) unsaturated section and a deep saturated-flow regime. The relevant data for analyzing the saturated system include the standard hydrologic parameters of permeability (or similar parameters such as transmissivity and hydraulic conductivity), hydraulic gradient, effective porosity, and water flux. For the unsaturated zone, the same parameters are needed, but they must be augmented with information on infiltration and percolation rates, the moisture content of the rock, and the relationship of moisture content or saturation to matric potential (suction) and hydraulic conductivity. For both the saturated and unsaturated zones, an understanding of the spatial distribution of these

Table 6-15. Summary of analyses for Section 6.3.1.1; geohydrology (10 CFR 960.4-2-1)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITIONS	
(1) Site conditions such that the pre-waste-emplacement ground-water travel time along any path of likely radionuclide travel from the disturbed zone to the accessible environment would be more than 10,000 years.	The evidence indicates that this favorable condition is present at Yucca Mountain: ground-water travel time along any path of likely radionuclide travel is expected to be more than 10,000 years.
(2) The nature and rates of hydrologic processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years.	The evidence indicates that this favorable condition is not present at Yucca Mountain: pluvial conditions that could cause changes in the water-table position and increase flux are expected to affect, but not significantly reduce, isolation potential in the next 100,000 years.
(3) Sites that have stratigraphic, structural, and hydrologic features such that the geohydrologic system can be readily characterized and modeled with reasonable certainty.	The evidence indicates that this favorable condition is not present at Yucca Mountain: no features are known that would prevent the site from being characterized and modeled after site characterization but available data are insufficient to model the site with reasonable certainty.
(4) For disposal in the saturated zone, at least one of the following pre-waste-emplacement conditions exists:	Condition does not apply to Yucca Mountain.

Table 6-15. Summary of analyses for Section 6.3.1.1; geohydrology (10 CFR 960.4-2-1) (continued)

Condition	Department of Energy (DOE) finding
(i) A host rock and immediately surrounding geohydrologic units with low hydraulic conductivities.	Condition does not apply to Yucca Mountain.
(ii) A downward or predominantly horizontal hydraulic gradient in the host rock and in the immediately surrounding geohydrologic units.	Condition does not apply to Yucca Mountain.
(iii) A low hydraulic gradient in and between the host rock and the immediately surrounding geohydrologic units.	Condition does not apply to Yucca Mountain.
(iv) High effective porosity together with low hydraulic conductivity in rock units along paths of likely radionuclide travel between the host rock and the accessible environment.	Condition does not apply to Yucca Mountain.
(5) For disposal in the unsaturated zone, at least one of the following pre-waste-emplacement conditions exists:	The evidence indicates that three of five of the subconditions of this favorable condition are present at Yucca Mountain:
(i) A low and nearly constant degree of saturation in the host rock and in the immediately surrounding geohydrologic units.	The degree of saturation in the host rock and surrounding geohydrologic units is spatially variable. Therefore, the subcondition is not present.

Table 6-15. Summary of analyses for Section 6.3.1.1; geohydrology (10 CFR 960.4-2-1) (continued)

Condition	Department of Energy (DOE) finding
(ii) A water table sufficiently below the underground facility such that the fully saturated voids continuous with the water table do not encounter the host rock.	The host rock contains no fully saturated voids that are continuous with the water table. Therefore, the subcondition is present.
(iii) A geohydrologic unit above the host rock that would divert the downward infiltration of water beyond the limits of the emplaced waste.	The bedded tuffs above the densely welded host rock may divert pulses of water, but not necessarily beyond limits of emplaced waste. Therefore, the subcondition is not present.
(iv) A host rock that provides for free drainage.	The host rock is expected to be freely draining. The subcondition is present.
(v) A climatic regime in which the average annual historical precipitation is a small fraction of the average annual potential evapotranspiration.	Precipitation in the area is about 20 percent of the potential evapotranspiration. Therefore, the subcondition is present.

POTENTIALLY ADVERSE CONDITIONS

(1) Expected changes in geohydrologic conditions--such as changes in the hydraulic gradient, the hydraulic conductivity, the effective porosity and the ground-water flux through the host rock and the surrounding geohydrologic units--sufficient to significantly increase the transport of radionuclides to the accessible environment as compared with pre-waste-emplacement conditions.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: expected changes in geohydrologic conditions are not likely to cause significant increase in transport of radionuclides.

Table 6-15. Summary of analyses for Section 6.3.1.1; geohydrology (10 CFR 960.4-2-1) (continued)

Condition	Department of Energy (DOE) finding
(2) The presence of ground-water sources, suitable for crop irrigation or human consumption without treatment, along ground-water flow paths from the host rock to the accessible environment.	The evidence indicates that this potentially adverse condition is present at Yucca Mountain: ground-water sources suitable for crop irrigation or human consumption are present along the ground-water flow paths, although resource potential is small.
(3) The presence in the geologic setting of stratigraphic or structural features--such as dikes, sills, faults, shear zones, folds, dissolution effects, or brine pockets--if their presence could significantly contribute to the difficulty of characterizing or modeling the geohydrologic system.	The evidence indicates that this potentially adverse condition is present at Yucca Mountain: fractures, fault zones, and dikes could contribute to the difficulty of characterizing and modeling the system.

QUALIFYING CONDITION

The present and expected geohydrologic setting of a site shall be compatible with waste containment and isolation. The geohydrologic setting, considering the characteristics of and the processes operating within the geologic setting, shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.

Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): radionuclide release is expected to be less than one part in 100,000 of the 1,000 year inventory; ground-water flow time is likely to be more than 10,000 years; the low magnitude of ground-water flux limits potential release of radionuclides.

properties is needed. This, in turn, requires a knowledge of the stratigraphy and structure of the proposed site, including the dip, character, thickness, depth, and lateral variations of the rock units and the frequency and orientations of fractures, faults, and other structures.

Five drill holes at Yucca Mountain (UE-25a#1, USW G-1, USW G-2, USW G-3/GU-3, and USW G-4) have been continuously cored to depths ranging from 760 to 1,825 meters (2,500 to 6,000 feet) (Spengler et al., 1979, 1981; Spengler and Chornack, 1984). Stratigraphic descriptions have been published for several of these holes (Spengler and Chornack, 1984; Maldonado and Koether, 1983; Scott and Castellanos, 1984). Test hole UE-25b#1 was cored from 579 to 1,220 meters (1,900 to 4,000 feet) (Lahoud et al., 1984). One test hole (UE-25p#1) penetrated pre-Tertiary rocks (Craig and Johnson, 1984) and provided both cuttings and core samples of Paleozoic rocks that underlie the section of Tertiary rocks east of Yucca Mountain (Craig and Robison, 1984). Rock property analyses of core samples from UE-25a#1 are available in Anderson (1981a). In addition, cuttings and cores from many nearby hydrologic test holes provided additional data on the positions of stratigraphic contacts. A summary of geologic studies at the Yucca Mountain site is presented in USGS (1984).

Test holes for hydrologic conditions include 14 holes that have been drilled to provide data on the altitude of the water table (Robison, 1984) and 3 holes drilled in the immediate vicinity of Yucca Mountain for pump and packer-injection tests (Rush et al., 1984; Lahoud et al., 1984; Craig and Robison, 1984). Data are also available from two deep test holes in the unsaturated zone, USW UZ-1 and USW UZ-6 (Henderson and Benson, 1983; Whitfield, 1985). Both were drilled using reverse-air vacuum drilling techniques, and core and cuttings were obtained. USW UZ-1, drilled to 366 meters (1,200 feet) has been instrumented to obtain potentiometric and moisture-content data. Plans are to install similar instrumentation in USW UZ-6, drilled to 579 meters (1,900 feet). Table 6-16 summarizes the published reports available on the saturated zone hydrologic drill holes at Yucca Mountain. Paleohydrologic data from the vicinity of Yucca Mountain are also available (Winograd and Doty, 1980).

A geologic map of Yucca Mountain shows patterns of structural features (Scott and Bonk, 1984). The major normal faults that subdivide the geologic setting of Yucca Mountain into a series of blocks tilted slightly to the east have been known for more than 20 years (Christiansen and Lipman, 1965; Lipman and McKay, 1965); they fit the descriptions of typical basin and range faults that occur elsewhere in the Great Basin (Scott et al., 1984). Major normal faults that have a vertical displacement of more than 70 meters (230 feet) have been identified on the basis of aeromagnetic surveys (Bath and Jahren, 1984) and can in some places be located where they occur under alluvium. The attitudes of faults and fractures at depth in drill holes are similar to those on the surface (Scott and Bonk, 1984; Scott and Castellanos, 1984). Quaternary movement on faults in the vicinity of Yucca Mountain has been investigated, and the results are summarized in Swadley et al. (1984). Fault-related mineral deposits, found in the Yucca Mountain area and their origin are discussed in Vaniman et al. (1985). Other references on the nature and rates of tectonic activity at Yucca Mountain are discussed in Section 6.3.1.7.

Table 6-16. Published geohydrologic well reports

Well	Data Reports	Interpretive Reports
USW H-1	Rush et al., 1983	Rush et al., 1984; Barr, 1985
USW H-3	Thordarson et al., 1984	Thordarson et al., 1985
USW H-4	Whitfield et al., 1984	Erickson and Waddell, 1985; Whitfield et al., 1985
USW H-5	Bentley et al., 1983	-----
USW H-6	Craig et al., 1983	-----
UE-25b#1	Lobmeyer et al., 1984	Lahound et al., 1984
UE-25p#1	Craig and Johnson, 1984	Craig and Robison, 1984
UE-29a#1,2	-----	Waddell, 1985
USW G-4	Bentley, 1984	-----
Well J-13	-----	Thordarson, 1983

The hydrostratigraphy of tuffs in the unsaturated zone (see discussion of geologic units in tables 6-17 and 6-18 in Section 6.3.1.1.5) consists of the following hydrogeologic units: the Tiva Canyon welded unit, the Paintbrush nonwelded unit, the Topopah Spring welded unit (including the proposed repository horizon), the Calico Hills nonwelded vitric unit, the Calico Hills nonwelded zeolitic unit, the Prow Pass welded unit, the Prow Pass nonwelded unit, the Bullfrog welded unit, and the Bullfrog nonwelded unit. Not all hydrogeologic units are present at any given location within the primary repository area at Yucca Mountain.

The Tiva Canyon welded hydrogeologic unit is the densely to moderately welded part of the Tiva Canyon Member of the Paintbrush Tuff. This unit is the uppermost stratigraphic layer that underlies much of Yucca Mountain. The Paintbrush nonwelded hydrogeologic unit consists of the nonwelded and partially welded base of the Tiva Canyon Member, the Yucca Mountain Member, the Pah Canyon Member, and associated bedded tuffs, all part of the Paintbrush Tuff. The lithology of this hydrogeologic unit is mostly thin, nonwelded ash-flow sheets and bedded tuffs, and in the primary repository area, the unit crops out only in a narrow band along Solitario Canyon (Montazer and Wilson, 1984).

The Topopah Spring welded hydrogeologic unit consists of a very thin upper vitrophyre, a thick central zone consisting of several densely welded devitrified ash-flow sheets, and a thin lower vitrophyre. The unit is highly fractured, and contains several lithophysal cavity zones (Montazer and Wilson, 1984).

The Calico Hills nonwelded unit is composed of the following stratigraphic units: the nonwelded base of the Topopah Spring Member; the tuffaceous beds of the Calico Hills which contain both zeolitic and vitric facies, and the upper part of the Prow Pass Member (Montazer and Wilson, 1984). Fracture frequency within this unit is much lower than in the overlying Topopah Spring welded unit. The water table is generally below the Calico Hills nonwelded unit, except beneath the eastern part of Yucca Mountain. Moisture flux beneath the repository horizon is quite low; an upper bound on the estimated range of flux is 0.5 millimeter (0.02 inch) per year (Wilson, 1985).

Two-dimensional modeling of flow in the saturated zone on a regional scale has been performed (Waddell, 1982; Czarnecki, 1985; Czarnecki and Waddell, 1984). Regional data for this modeling have been obtained from Winograd and Thordarson (1975). Hydrologic and hydraulic data in the immediate vicinity of Yucca Mountain have been obtained by the following methods, and are documented in the following sources. Bulk saturated hydraulic conductivity of the Topopah Spring welded unit is known from pumping tests in Well J-13 (Thordarson, 1983) where this unit occurs in the saturated zone. The results of pumping tests and packer-injection tests on three test holes in the immediate vicinity of Yucca Mountain are presented by Rush et al. (1984), Lahoud et al. (1984), and Craig and Robison (1984). In addition, 14 other test holes have been drilled that provide data on altitude of the water table (Robison, 1984). Bulk and fracture effective porosities in the saturated zone have been calculated and are reported by Sinnock et al. (1984). Information provided in Freeze and Cherry (1979) was used in the calculation of effective porosities.

A general conceptual model for flow through the unsaturated zone has also been developed (Scott et al., 1983; Montazer and Wilson, 1984). A stochastic model for calculation of velocities and travel time in the unsaturated zone was developed by Sinnock et al. (1986), and information from Brooks and Corey (1966) was used to account for the effect of pore-size distribution on velocity. Information concerning the in situ distribution of moisture in the unsaturated formations at Yucca Mountain is available from various boreholes (Weeks and Wilson, 1984; Montazer and Wilson, 1984; Palaz, 1985; Peters et al., 1984; Montazer et al., 1985). Rock-mass permeabilities to air in the Topopah Spring Member are summarized in Montazer and Wilson (1984) and are considered to be an indirect indication of the potential for drainage (Montazer, 1982). Porosity values for the tuffaceous beds of the Calico Hills, which underlie the Topopah Spring Member, are given by Weeks and Wilson (1984), Montazer and Wilson (1984), and Peters et al. (1984). The matrix hydraulic conductivity of the Topopah Spring unit, as well as of other units, has been obtained from laboratory measurements of cores and cuttings (Montazer and Wilson, 1984). Saturated matrix hydraulic conductivity values for the Calico Hills unit and for the Prow Pass and Bullfrog members of the Crater Flat Tuff have been obtained from the Tuff Data Base (SNL, 1985). Laboratory tests indicate that a relationship may exist between matrix

hydraulic conductivity and lithology (Lappin et al., 1982). Data presented in Blankennagel and Weir (1973) demonstrate this relationship for tuffs beneath Pahute Mesa. Additional hydrogeologic data is presented in Winograd and Thordarson (1975).

Meteorological data from several stations in the region are presented by Bowen and Egami (1983) and Quiring (1983). Potential evapotranspiration for Yucca Mountain has been estimated by an empirical method reviewed in Rosenberg (1974). Climates of the Nevada Test Site and vicinity during the last 45,000 years have been reconstructed in Spaulding (1983) and Spaulding et al. (1984). Possible climatic responses to increases in atmospheric carbon dioxide are presented in Kukla and Gavin (1981) and Etkins and Epstein (1982). The influence of earth's orbital variations on climatic changes is discussed in Imbrie and Imbrie (1980). Other relevant climatological data are presented in Section 6.3.1.4, Climatic changes. A water-budget study for eastern Nevada is described by Eakin et al. (1951). The study utilizes a technique developed by Maxey and Eakin (1949) to estimate ground-water recharge. In Rush (1970), the technique was applied to estimate average annual recharge for basins in the Nevada Test Site area. The method described by Eakin et al. (1951) has been evaluated in Watson et al. (1976). An estimate of the water resource potential beneath Yucca Mountain is provided in Sinnock and Fernandez (1982).

Assumptions and data uncertainties

The principal assumptions that must be made about the hydrologic system of Yucca Mountain involve the amount of recharge, the related ground-water flux through the unsaturated zone, and the mechanisms by which water moves in the unsaturated tuffs. There is uncertainty about the most representative values for hydraulic conductivities, moisture contents, and effective porosities of the various rock units traversed by the subsurface water at Yucca Mountain. Effective porosities are subject to considerable uncertainty. To compensate for the inherent uncertainty in the existing information, most assumptions in this section are conservative, and, thus, they are believed to reasonably bound the probable range of hydrologic behavior at Yucca Mountain. Therefore, despite the uncertainty about the exact conditions and processes of the hydrologic system at Yucca Mountain, especially in the unsaturated zone, the conservatism of the assumptions and analyses allows confidence in the general conclusions about the hydrologic system.

A general conceptual model of flow in the unsaturated zone has been developed (Montazer and Wilson, 1984). The model is based on (1) current understanding of the hydrogeologic framework, (2) application of the principles of unsaturated flow, and (3) interpretation of preliminary data from ongoing field and laboratory investigations. The conceptual model is presented as a single comprehensive model, but it is broad enough and flexible enough to accommodate various alternative hypotheses for unsaturated flow conditions. These hypotheses are being tested by computer simulations that incorporate realistic ranges of input parameters and boundary conditions.

The results of both quantitative and qualitative analyses are used in the following discussions. Quantitative analyses are used to predict (1) the

expected ground-water travel time from the repository to the accessible environment in the evaluation against the disqualifying condition and (2) the expected releases of radionuclides to the accessible environment in the evaluation against the qualifying condition. Qualitative analyses are used to establish whether Yucca Mountain possesses the several favorable and potentially adverse conditions. Semiquantitative analyses are used in these evaluations to help draw conclusions from the information collected about the site and to incorporate other pertinent information from reasonable natural analogs of the site. For purposes of interpreting the favorable condition for ground-water travel time, the current position expressed by the Nuclear Regulatory Commission regarding extreme values in travel-time distribution (Browning, 1985) was considered in the analysis.

6.3.1.1.3 Favorable conditions

- (1) Site conditions such that the pre-waste-emplacement ground-water travel time along any path of likely radionuclide travel from the disturbed zone to the accessible environment would be more than 10,000 years.

Evaluation

A complete discussion of the calculation of ground-water travel time at Yucca Mountain is included in the disqualifying condition evaluation (Section 6.3.1.1.5). The stochastic approach taken to evaluate ground-water travel time produces a distribution of possible travel times. The distribution results from natural variability and uncertainty in the hydrologic parameters. Conservative assumptions built into the flow model serve to shift the distribution to lower travel times. The extreme upper and lower portions of the travel-time distribution are characteristic of travel times along unlikely paths of radionuclide travel and therefore are inappropriate for evaluating this favorable condition. The U.S. Department of Energy (DOE) considers this judgment to be consistent with the Nuclear Regulatory Commission (NRC) staff position regarding the ground-water travel time requirement in 10 CFR Part 60 (Browning, 1985).

At this stage, the selection of an absolute value for the probability of travel times greater than 10,000 years is not warranted. The data base resulting from site characterization will permit better parameter estimation with less uncertainty and a more realistic construction of the travel-time model. These improvements are expected to narrow the range of travel times sufficiently to allow consideration of an appropriate probability value.

For the interim, a measure of central value of the travel-time distribution is considered appropriate for evaluating the potential site against this favorable condition. The mean is a mathematical approximation of the expected travel time (Davenport, 1970), and the median is also a measure of central value. For this reason, both mean and median values are provided in this evaluation, and both exceed 10,000 years. For the upper bound to the estimated range of flux through the repository of 0.5 millimeter (0.02 inch) per year, the mean travel time is approximately 43,405 years; the median travel time is about 41,750 years; and the range of travel times between the

disturbed zone and the accessible environment is from about 9,500 to 80,235 years (Table 6-20). These travel times include 140 years estimated for a 5-kilometer (3-mile) flow path in the saturated zone.

Ten computer realizations of travel time were made for each of 963 columns which represent the rock volume between the disturbed zone and the water table. Of the 9,630 realizations of travel time, 9,629 resulted in travel-time values greater than 10,000 years. Only one out of 9,630 realizations of the travel-time model resulted in a travel time less than 10,000 years. Therefore, for purposes of this evaluation the evidence indicates that this favorable condition is present.

Conclusion

Available data and current understanding of the geohydrologic system indicate that for the estimated upper bound on flux of 0.5 millimeter (0.02 inch) per year, the travel time along any path of likely radionuclide travel from the disturbed zone to the accessible environment is greater than 10,000 years. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(2) The nature and rates of hydrologic processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years.

Evaluation

The Quaternary Period was characterized by cyclic fluctuations of climate, with wetter, cooler pluvial periods alternating with dryer, warmer interpluvial periods. Thus, at times, changes in hydrologic phenomena were related to increases in the available moisture, and, at other times, changes were associated with drying conditions. The principal changes in hydrologic processes that are associated throughout the Quaternary with the onset of pluvials occurred most recently about 9,000 to 13,000 years ago and probably included increasing recharge and a rising water table, with attendant changes in hydraulic gradients and the upgradient movement of ground-water discharge sites. Quaternary climatic conditions are described in more detail in Section 6.3.1.4 (Climatic changes).

The most recent climatic trend results from the shift from pluvial to interpluvial conditions that has led to the conditions observed today (Winograd and Doty, 1980). This trend (decreasing recharge, declining water table, and down-gradient shifts in ground-water discharge sites), if continued, would be likely to affect favorably the isolation capability of the repository. For the Ash Meadows ground-water basin, Winograd and Doty (1980) cited calcitic vein fracture fillings and ancient lakebed deposits as evidence that the water-table altitude in the regional carbonate aquifer during past pluvial conditions may have been as much as 50 meters (160 feet) higher than the modern level. Preliminary modeling results (Czarnecki, 1985) using the regional hydrologic models developed by Waddell (1982) and Czarnecki and Waddell (1984) suggest that water-table altitudes at and near

Yucca Mountain could possibly rise in the future as much as 130 meters (426 feet) above the current position of the water table. The simulation that predicted a water-table rise of this magnitude was based on assumptions that are conservative and may not be realistic (see Section 6.3.1.4.3). Nevertheless, cyclic fluctuations in climate are expected to continue and pluvial conditions are likely to return in the 100,000 year time frame covered by this favorable condition. Although there is considerable uncertainty in the changes that would occur during a return to pluvial conditions, increased recharge and increases in water-table altitude are likely in some portions of the Death Valley ground-water system. These changes would be unlikely to favorably affect the ability of a repository at Yucca Mountain to isolate waste.

Other processes of interest during the Quaternary are discussed in the evaluation of the geochemistry guideline (Section 6.3.1.2) and the erosion guideline (Section 6.3.1.5). According to those discussions, the past rates of other processes that depend on hydrologic processes, such as erosion, mineral dissolution, and mineral precipitation, remained at a low and relatively constant rate during the Quaternary Period.

Conclusion

The nature and rates of the hydrologic processes that operated at Yucca Mountain during the Quaternary Period were influenced by cyclic fluctuations in precipitation and a possible trend of increasing aridity. The nature and the rates of these processes if continued into the future could have an effect on the ability of the geologic repository to isolate radioactive waste during the next 100,000 years. Increased flux together with increased water table altitude could shorten the travel time through the unsaturated portion of the flow path, thus decreasing the total travel time to the accessible environment. Therefore, the evidence indicates that this favorable condition is not present at Yucca Mountain.

(3) Sites that have stratigraphic, structural, and hydrologic features such that the geohydrologic system can be readily characterized and modeled with reasonable certainty.

Evaluation

The geologic setting of Yucca Mountain is complex, with rocks ranging in age from Precambrian through Holocene, and the area has undergone many periods of structural deformation. Because of the weapons testing at the Nevada Test Site since the early 1960s, extensive geologic, geophysical, and hydrologic studies have been completed, and the geology and hydrology of the Nevada Test Site region are well documented. Extensive study of the nearby Yucca Mountain area started in 1978. Since that time, the geologic and hydrologic knowledge of the Yucca Mountain area has been greatly expanded.

Yucca Mountain is composed of block-faulted Tertiary ash-flow, air-fall, and bedded tuffs. The material properties used to model the geohydrologic system (e.g., porosity, matrix permeability, fracture permeability, relationships between moisture content and matric potential, and geochemical characteristics) vary substantially in this type of geologic setting. Although regional ground-water flow has been modeled (Waddell, 1982; Czarnecki and

Waddell, 1984), the physics of moisture movement in thick, unsaturated, fractured rocks is complex, and only preliminary conceptual models are available (Scott et al., 1983; Montazer and Wilson, 1984).

The general stratigraphic features of Yucca Mountain are well known as a result of studies listed in the section on relevant data. The general structural character of Yucca Mountain is also well known. Geologic maps of Yucca Mountain show patterns of structural features (Scott and Bonk, 1984; Christiansen and Lipman, 1965; Lipman and McKay, 1965). The attitudes of faults and fractures that are observed at depth in drill holes correlate well with those on the surface (Scott and Bonk, 1984; Scott and Castellanos, 1984). Thus, major surface structural features can be used to characterize the subsurface stratigraphy and geologic structures, the details of which would be determined during site characterization.

A relationship between lithology and permeability, based on well yields for welded tuffs, rhyolites, and bedded tuffs beneath eastern Pahute Mesa was demonstrated by Blankennagel and Weir (1973). A similar relationship may exist at Yucca Mountain. Laboratory tests of cores from both geologic and hydrologic test holes (Anderson, 1981a; Lappin et al., 1982; Peters et al., 1984; Rush et al., 1984; Weeks and Wilson, 1984) indicate that the porosity and the hydraulic conductivity of the matrix decrease as the degree of welding increases; however, fracture porosity increases and bulk permeability may increase with increased welding. Winograd and Thordarson (1975) and Scott et al. (1983) conclude that fracture frequency increases with the degree of welding.

These data and observations, together with the stratigraphic and structural data, have been used to develop conceptual models for flow through the unsaturated zone (Scott et al., 1983; Montazer and Wilson, 1984). These conceptual models represent the current hypotheses of the framework and dynamics of the flow system and are derived from preliminary data, from principles of saturated and unsaturated flow, and from the literature. The conceptual models form the basis upon which computer models and simple mathematical models are designed. Alternative concepts of flow can be tested with the models to derive the system with the framework, boundary, and flow characteristics that conform best with the observed data.

Hydrologic testing of the saturated zone has been performed on three test holes in the immediate vicinity of Yucca Mountain. These tests have included pumping tests of all or part of the saturated zone penetrated by the wells and packer-injection tests of isolated intervals within the holes. Both hydraulic-conductivity and water-level data have been collected. The results are presented by Craig and Robison (1984), Rush et al. (1984), and Lahoud et al. (1984). In addition, 14 other holes provided data on the altitudes of the water table (Robison, 1984). The results of these studies show that in the saturated zone at Yucca Mountain, ground water flows mainly through fractures in the welded tuffs. Productive intervals in test holes are controlled mostly by the distribution of permeable fractures that are intercepted by the hole rather than by stratigraphic position in the densely welded units. Therefore, attempts using only testing results to define the position or spatial extent of hydrogeologic units have not been successful. However, a relationship between lithology and fracture frequency at Yucca

Mountain has been documented by Scott et al. (1983) and may allow the general distribution of transmissive zones to be determined.

Existing data regarding the spatial extent and hydrologic properties of the hydrogeologic units at Yucca Mountain are sufficient to allow preliminary definition of flow properties (Czarnecki and Waddell, 1984; Czarnecki, 1985; and Montazer and Wilson, 1984). Computer models and simple mathematical calculations can then be used to determine the range of likely flow conditions. As more data are collected and more sophisticated hydrologic computer models are developed during site characterization, the range that encompasses possible flow conditions will be narrowed. Statistical methods will be used to determine the sensitivity of estimates of hydrologic flow conditions to the uncertainty in data and models. Conclusions about the hydrologic system of Yucca Mountain can then be derived by either of the following two approaches:

1. Using a set of reasonably conservative properties in the analyses (i.e., by using values from each end of the uncertainty range to derive the shortest flow time or the greatest flow volume).
2. Statistically sampling from the expected distribution of values for each property to develop a probability distribution for net flow conditions.

When considered together, these two approaches will provide increased confidence about the possible range and the most likely conditions for the hydrologic system at Yucca Mountain.

The degree to which uncertainty in the hydrologic models for Yucca Mountain must be reduced depends on whether the uncertainty jeopardizes confidence in the ability of the site to meet performance standards. Hydrologic tests planned for site characterization will greatly improve the confidence that can be placed in models of the Yucca Mountain site; they will provide important data for the validation of hydrologic models. Although the site cannot be readily characterized as defined by this favorable condition, a sufficient data base will be obtained during site characterization to allow the hydrologic system of Yucca Mountain to be modeled with reasonable certainty.

Conclusion

Detailed geologic mapping and drilling at Yucca Mountain and in its vicinity have demonstrated that the stratigraphic and structural features of Yucca Mountain are complex, but site characterization is expected to provide the data needed to model the site with reasonable certainty. The groundwater flow at Yucca Mountain from the land surface to the repository, from the repository to the water table, and laterally from the water table to the accessible environment can be characterized and modeled by techniques that establish reasonable bounds on critical hydrologic parameters. However, data currently available do not allow the site to be readily characterized and modeled with reasonable certainty. Therefore, the evidence indicates that this favorable condition is not present at Yucca Mountain.

(4) For disposal in the saturated zone, at least one of the following pre-waste-emplacement conditions exists:

- (i) A host rock and immediately surrounding geohydrologic units with low hydraulic conductivities.
- (ii) A downward or predominantly horizontal hydraulic gradient in the host rock and in the immediately surrounding geohydrologic units.
- (iii) A low hydraulic gradient in and between the host rock and the immediately surrounding geohydrologic units.
- (iv) High effective porosity together with low hydraulic conductivity in rock units along paths of likely radionuclide travel between the host rock and the accessible environment.

Conclusion

This condition does not apply to Yucca Mountain because disposal will not occur in the saturated zone.

(5) For disposal in the unsaturated zone, at least one of the following pre-waste-emplacement conditions exists:

- (i) A low and nearly constant degree of saturation in the host rock and in the immediately surrounding geohydrologic units.
- (ii) A water table sufficiently below the underground facility such that the fully saturated voids continuous with the water table do not encounter the host rock.
- (iii) A geohydrologic unit above the host rock that would divert the downward infiltration of water beyond the limits of the emplaced waste.
- (iv) A host rock that provides for free drainage.
- (v) A climatic regime in which the average annual historical precipitation is a small fraction of the average annual potential evapotranspiration.

Evaluation for the degree of saturation in the host rock

Information concerning the in situ distribution of moisture in the unsaturated formations at Yucca Mountain is available from various boreholes (Palaz, 1985; Montazer et al., 1985; Montazer and Wilson, 1984; and Weeks and Wilson, 1984). Results indicate that saturation in the Topopah Spring welded unit is quite variable. For example, in 44 samples reported by Montazer and Wilson (1984), saturation ranged from 40 to 90 percent, with a mean of about 65 percent and a standard deviation of about 20 percent. The wide variability is partly the result of measurement errors caused by the low porosity of the unit. In addition, in rocks with low porosity, slight variation in

pore size and water content causes relatively large variation in percent saturation.

Evaluation for the extent of fully saturated voids

The water table is 500 to 750 meters (1,600 to 2,500 feet) below the land surface (Robison, 1984), and 200 to 400 meters (656 to 1,300 feet) below the repository horizon. The zone of continuous, fully saturated voids is not expected to extend above the top of the Calico Hills nonwelded unit (Montazer and Wilson, 1984). The contrast between the fractured Topopah Spring welded unit and the porous Calico Hills nonwelded unit is likely to cause a capillary barrier that would retard upward flow from the pores of the Calico Hills nonwelded unit into the fractures of the Topopah Spring welded unit. Water could move into the matrix of the Topopah Spring welded unit, but only at an extremely low rate because of the low permeability. Measurements of the degree of saturation for the matrix of the Topopah Spring welded unit (mean of 65 percent, standard deviation of 20 percent) indicate that the pores of the host rock are not continuous, fully saturated voids (Montazer and Wilson, 1984).

Evaluation for the diversion of infiltration

Conditions exist at Yucca Mountain that are believed to promote unsaturated lateral flow that diverts downward infiltration of water. These conditions include the presence of dipping anisotropic units of contrasting properties (Montazer and Wilson, 1984). Under these conditions, a horizontal gravitational component of the potential gradient can be induced along the contacts between layers, resulting in down-dip flow even at very low saturations. Dips of the upper units are 3 to 8° to the east (USGS, 1984), and the overall lateral hydraulic conductivity of the Paintbrush nonwelded unit is much greater than the vertical hydraulic conductivity of this unit (Montazer and Wilson, 1984). The result is that more than 100 millimeters (4 inches) of lateral flux can be transmitted per year, assuming uniform lateral distribution of matric potential (Montazer and Wilson, 1984).

The potential for lateral flow at Yucca Mountain is enhanced by the presence of alternating nonwelded units and welded units. The contrasting properties of these two types of units can result in the formation of capillary and permeability barriers. The Paintbrush nonwelded unit, which overlies the Topopah Spring welded unit, is highly porous and relatively unfractured (Montazer and Wilson, 1984; Scott et al., 1983). The Topopah Spring welded unit, on the other hand, is highly fractured and has an extremely low matrix permeability (Montazer and Wilson, 1984). The contrasts between these two hydrogeologic units are expected to create capillary and permeability barriers that retard the downward flow of water from the matrix of the Paintbrush nonwelded unit into the Topopah Spring welded unit. A capillary barrier probably is formed between the matrix of the Paintbrush nonwelded unit and the fractures of the Topopah Spring welded unit. This barrier would form where water-filled pores in the nonwelded unit are smaller than the apertures of fractures in the underlying welded unit. Furthermore, the low matrix permeability of the Topopah Spring welded unit restricts the downward movement of water into the matrix of this unit.

Barriers may also exist at the upper contact of the Paintbrush nonwelded unit. The Tiva Canyon welded unit, which overlies this nonwelded unit and crops out at the surface, is highly fractured and transmissive. Its bulk permeability is estimated to be as much as a 3,000 times the bulk permeability of the underlying nonwelded unit. According to current conceptual models, during a major infiltration event recharging water would readily percolate down the fractures of the Tiva Canyon welded unit. If the event were intense and short lived, water that reached the upper boundary of the Paintbrush nonwelded unit would tend to move down dip at this boundary. This down dip flow would occur because of the initial difference in the permeability of the two units and because the pulse of water would temporarily trap air in the upper part of the nonwelded unit, thereby significantly decreasing the effective permeability to water. This lateral movement at the upper boundary would continue until structural features with high permeability were encountered.

The effectiveness of these conditions in actually causing lateral flow at Yucca Mountain is not known. Flux estimates are not definitive, but indicate that flux above the Topopah Spring welded unit probably is greater than within the unit in the primary repository area (Montazer and Wilson, 1984; see also discussion, Section 6.3.1.1.5).

Postulated lateral flow would move down dip until reaching structural features that have sufficient permeability to divert the flow. It is not yet established whether features such as the Ghost Dance fault and the fault zones that bound the primary repository area are such features. If such highly permeable features exist, they could serve as conduits for downward flow through the unsaturated section. However, percolating water cannot be conclusively demonstrated to be diverted beyond the limits of the emplaced waste as required by this subcondition, because the Ghost Dance fault, which occurs within the primary repository area, may act as one of these conduits.

Evaluation for free drainage

Free drainage of the host rock is considered to be a favorable condition because such a condition would allow water to move rapidly through the unit, thus minimizing potential contact time with waste disposal containers. The Topopah Spring welded unit is considered to be freely draining because its permeable fracture network would allow rapid flow if flux were to increase sufficiently to cause fracture flow.

The free-drainage characteristics of the Topopah Spring welded unit can be inferred from the pervasive and abundant fractures and the hydraulic properties of the unit. Welded units have relatively more abundant fractures (15 to 40 fractures per cubic meter) than the nonwelded units (as few as 1 fracture per cubic meter) in the subsurface at Yucca Mountain, which results in large bulk permeability. Thordarson (1983) reported a hydraulic conductivity of 1 meter (3.28 feet) per day for the Topopah Spring Member at Well J-13, where this unit occurs in the saturated zone. This hydraulic conductivity must be derived mostly from fractures; average saturated matrix hydraulic conductivity for the Topopah Spring welded unit, based on analyses of 31 core samples, is 0.722 millimeter (0.03 inch) per year or 1.97×10^{-6} meter (6.1×10^{-7} foot) per day (see Table 6-17 in Section 6.3.1.1.5). The high bulk permeability in the unsaturated zone is also reflected in the

extensive loss of drilling fluid in the Topopah Spring Member during the drilling of geologic core holes at Yucca Mountain (Spengler et al., 1981).

Rock-mass permeabilities to air have been determined for the unsaturated Topopah Spring welded unit to a depth of about 100 meters (328 feet) below the land surface (Montazer et al., 1985). Preliminary results show that this unit has permeabilities to air of 1×10^{-7} to 7×10^{-9} square centimeters (approximately equivalent to saturated hydraulic conductivities of 0.6 to 10 meters per day). Permeabilities in this range must be dominated by fractures because measurements of saturated matrix hydraulic conductivities are on the order of 1 millimeter (0.04 inch) per year. Similar conditions are expected deeper in the Topopah Spring welded unit, on the basis of preliminary data from drill hole USW UZ-1 and known high fracture frequencies (Scott et al., 1983). The ratio of permeabilities to air and water for unsaturated rocks indirectly indicates the potential for drainage.

The fractured, welded tuff of the host rock is known from drill-hole data to be continuous beneath the site (USGS, 1984); thus, free drainage conditions within this unit are expected throughout. However, it should be noted that some fractures are likely to be impermeable because of secondary mineral precipitation in the fracture openings. According to the conceptual model of Montazer and Wilson (1984), lateral flow may occur along the top of the Calico Hills nonwelded unit, possibly resulting in perching near major faults, at the base of the Topopah Spring welded unit. However, such an occurrence would be below the repository horizon, and therefore, would not affect free drainage through the repository.

No perched water was observed in the one unsaturated zone borehole (USW UZ-6) that has been drilled within the primary repository area and that penetrated the full section of the Topopah Spring welded unit (Whitfield, 1985). This borehole, located on Yucca Ridge, was drilled using a vacuum reverse-air-circulation drilling method, one that would permit ready identification of perched zones if encountered. Future investigations will evaluate the possible occurrence of perched water at the base of the unit near the Ghost Dance fault.

Perched water may have been observed in two boreholes adjacent to the primary repository area. These boreholes (USW UZ-1 and USW H-1) are located in Drill Hole Wash, in a hydrogeologic setting where perched water might be expected, according to the current hydrologic model of Yucca Mountain. Water sampled from the bottom of USW UZ-1 (at 387 meters (1,270 feet)) in the Topopah Spring welded unit) contained hydrocarbons similar to those in polymers used in the drilling fluid for USW G-1 about 305 meters (1,000 feet) away (Henderson and Benson, 1983; Whitfield, 1985). Thus, the water is believed to contain drilling fluid from USW G-1, but no determination was made that naturally occurring water also was present.

By means of a downhole television camera, small water seeps were observed entering the well bore of USW H-1 from fractures in the Topopah Spring Member (Rush et al., 1984). This well was drilled with a drilling fluid of air foam, consisting of detergent and water and large volumes of air; about 2.2 million liters (5.8×10^5 gallons) of water was used during drilling (Rush et al., 1984). No samples of the water seeping into the hole

were obtained, and it could not be determined whether the water was drilling fluid or perched water (Rush et al., 1984).

Evaluation for climatic regime

The meteorological recording stations at Yucca Mountain have not been operational long enough to yield historically significant precipitation records. Such records do exist, however, for several stations in the region (Bowen and Egami, 1983; Quiring, 1983). The annual average precipitation at Yucca Flat, 40 kilometers (25 miles) northeast of Yucca Mountain is 145 millimeters (5.7 inches); at Beatty, 26 kilometers (16 miles) to the west of Yucca Mountain, the annual average precipitation is 114 millimeters (4.5 inches). Precipitation at Yucca Mountain probably is slightly higher than that at Yucca Flat or Beatty, because of the terrain and the higher elevation. Average precipitation was estimated to be 150 millimeters (5.9 inches) per year for an area approximately equivalent to the primary repository area, which has an altitude range from about 1,200 to 1,465 meters (3,940 to 4,805 feet) (Montazer and Wilson, 1984, using information from Quiring, 1983).

Potential evapotranspiration was estimated by an empirical method reviewed in Rosenberg (1974) that uses a yearly heat index and mean monthly temperatures (the Thornthwaite method). Potential evapotranspiration for Yucca Mountain, corrected for actual sunshine hours, is about 630 millimeters (24.8 inches) per year. Therefore, the average annual precipitation, about 150 millimeters (5 to 6 inches), is about 20 percent of the annual potential evapotranspiration.

It should not be inferred from this condition that all precipitation at Yucca Mountain is evaporated. Intense summer storms and melting of winter snows undoubtedly result in pulses of infiltration that reach depths that are beyond the effects of evapotranspiration (i.e., net infiltration, or recharge, occurs).

Conclusion

The host rock and the immediately surrounding hydrogeologic units are not characterized by a low and nearly constant degree of saturation. The host rock is 200 meters (656 feet) or more above the water table and completely above the zone of continuous fully saturated voids. The Paintbrush nonwelded unit, about 30 meters (100 feet) thick, overlies the Topopah Spring welded unit and will probably serve as a buffer to divert pulses of water, but not necessarily beyond the limits of emplaced waste. The highly fractured host rock would provide free drainage if fracture flow were to occur. Precipitation is estimated to be less than 20 percent of potential evapotranspiration. Therefore, the evidence indicates that three of the five favorable conditions for disposal in the unsaturated zone are present at Yucca Mountain.

6.3.1.1.4 Potentially adverse conditions

(1) Expected changes in geohydrologic conditions--such as changes in the hydraulic gradient, the hydraulic conductivity, the effective porosity, and the ground-water flux through the host rock and the surrounding geohydrologic units--sufficient to significantly increase the transport of radionuclides to the accessible environment as compared with pre-waste-emplacement conditions.

Geohydrologic conditions can be affected by both construction-induced and naturally occurring processes. Construction-induced changes generally would be confined to a small volume of rock in the immediate vicinity of the repository and its shafts. Such changes are discussed further under the guideline for rock characteristics (Section 6.3.1.3).

Natural changes in geohydrologic conditions may occur either in the immediate vicinity of the repository or at greater distances from the repository. The changes that might be expected include (1) changes in the rate of ground-water recharge caused by climatic changes, (2) increased hydraulic conductivity or changes in the spatial relationships among hydrogeologic units caused by tectonic movement, (3) changes in the effective porosity caused by an increase in the number of fractures or by an increase or decrease in their apertures, and (4) changes in the vertical distance to the zone of saturation and, therefore, in the estimated radionuclide transport time to the accessible environment.

Evaluation for climatic changes

Major global climatic fluctuations probably will occur within the next 100,000 years, according to current knowledge of the dynamics of climate and the geologic and climatic records of past changes. The causes of climatic changes include increases in the global atmospheric concentration of carbon dioxide and changes in the earth's orbit. The possible climatic effects of these changes (Spaulding, 1983; Spaulding et al., 1984) are summarized below.

A substantial increase in carbon dioxide in the atmosphere would increase the radiative heating of the earth's surface and result in the melting of the Antarctic ice cap (Kukla and Gavin, 1981; Etkins and Epstein, 1982). The subsequent rise in sea level would not directly affect the Yucca Mountain site, but temperatures could increase by 3°C (5°F) or more, and summer rainfall would increase.

The configuration of the earth's orbit partly controls the solar radiation received by the earth, and changes in the precession, obliquity, or eccentricity of the orbit may be the principal causes of ice ages (Imbrie and Imbrie, 1980). If so, orbital changes would continue to influence the cooling trend of the last 6,000 years, with a glacial stage resulting in about 23,000 years and a glacial maximum, similar in magnitude to that of the late Wisconsin maximum (about 18,000 years ago) resulting in about 60,000 years. A return to pluvial climates would mean an increase in effective moisture, but valley floors would remain semiarid. The annual precipitation could be assumed to be as much as 100 percent higher than that at present. The mean annual temperature would be 6 to 7°C (11 to 13°F) lower than that at present (Spaulding et al., 1984).

Evaluation of effects of climatic changes on flow characteristics

The effects of a return to pluvial climatic conditions include the likelihood of increased recharge at Yucca Mountain. Associated with the increased recharge could be increased unsaturated zone flux and fracture flow; increased water-table altitude; modified and shortened unsaturated zone flow paths; and modified saturated zone flow paths, hydraulic gradients, and ground-water velocities.

The amount of increased recharge that would occur under a return to pluvial conditions is highly uncertain and would depend upon a variety of interrelated factors. These factors include not only the amount of increase in average annual precipitation, but the seasonal distribution and type of precipitation; the amount and rate of snowmelt; and changes in evapotranspiration, runoff characteristics, and soil and plant cover. Czarnecki (1985) estimated that, for an assumed 100 percent increase in precipitation (based on Spaulding et al., 1984), the ground-water recharge rate would be about 15 times the modern-day recharge rate. See Section 6.3.1.4.3 for a discussion of uncertainties in this recharge estimate. The estimate was made by applying the empirical technique of Eakin et al. (1951), and it does not take into account the factors listed above; therefore, it principally provides an indication that recharge increases could be greater than precipitation increases. The impacts of the increased recharge on the distribution and nature of flux in the unsaturated zone are unknown. Fracture flow may occur in the Topopah Spring welded unit, but the continued effectiveness of lateral flow and capillary and permeability barriers in maintaining low flux through the host rock is unknown.

Increased recharge probably would result in an increased altitude of the water table. Using the conservative increase in recharge rate of 15 times the modern value and other conservative assumptions, Czarnecki (1985) simulated a water-table rise of about 130 meters (427 feet) (Section 6.3.1.4) beneath Yucca Mountain. This amount would not result in inundation of the repository, but much of the Calico Hills nonwelded unit would become saturated. Flow velocities and pathways in this unit would change because of the change from unsaturated to saturated conditions, which would result in increased hydraulic conductivity and effective porosity and decreased hydraulic gradient.

The computer simulations of Czarnecki (1985) indicated that, as a result of increased recharge, changes in the direction of ground-water flow at and near the primary repository area would be small, but vertically integrated flux vectors would have a more southerly component. Saturated zone flux magnitude would increase 2 to 4 times near the primary repository area, resulting in decreased ground-water travel times to the accessible environment. The simulations also showed that ground-water discharge areas would occur upgradient from their present locations, but they still would be beyond the accessible environment boundary and, thus, would not necessarily affect the transport of radionuclides to the accessible environment.

No evidence has been found for modern or Quaternary springs or seeps on the flanks of Yucca Mountain, despite many detailed field investigations at the site. Potential spring deposits of calcite, silica, and sepiolite associated with faults have been observed in trenches in the immediate

vicinity of Yucca Mountain. Preliminary conclusions are that these deposits formed at or near surface temperatures, and that there is no evidence to indicate an origin different from the pedogenic process that resulted in similar mineral assemblages in sand ramps near the site (Vaniman et al., 1985).

Water from any future springs or seeps that might develop on the flanks of Yucca Mountain during periods of increased recharge would not pass through the repository, because the flow would be perched and the repository would be at a lower elevation than such springs. Water moving through the repository would enter the saturated ground-water system locally and travel toward the regional discharge areas.

Evaluation of effects of changes in water-table altitude

A discussion of the potential effects of changes in the position of the water table on transport of radionuclides to the accessible environment is presented in Section 6.3.1.4.4. Assuming that the water table rises to its maximum pluvial position, matrix diffusion and other retardation mechanisms are expected to delay the transport of radionuclides to the accessible environment so that U.S. Environmental Protection Agency release limits would not be exceeded (see sections 6.3.1.2.3 and 6.3.1.4.4).

Evaluation of effects of tectonic movement

The Basin and Range Province is tectonically active and is characterized by earthquakes and past volcanic activity (Section 6.3.1.7). Faults of Quaternary age occur near Yucca Mountain (Swadley et al., 1984). Future fault movement is shown in Section 6.3.1.7.5 to be unlikely to significantly affect the geohydrologic system at Yucca Mountain. The rate of tectonic activity is also likely to be slow enough that displacement of hydrogeologic units over the next 10,000 years is expected to be insignificant.

The primary repository area is relatively free from faulting as compared with the surrounding areas; however, the host rock is a densely welded tuff, and the frequency of fractures is expected to be high. The unsaturated host rock is free draining, and an increase in the number of fractures caused by renewed faulting generally would not be detrimental. Movement along a fault cutting the repository is not likely to have a significant effect on the flux of water through the host rock, which would be expected to remain quite low. However, if new faults penetrated units above the host rock, additional water may be intercepted and transmitted into the host rock if the fault zone was more permeable than surrounding rock matrix. Any effect on the rate of waste dissolution would be slight because of the overall low flux.

Tectonic movement at Yucca Mountain could result in an increase in the number of fractures in the Calico Hills nonwelded unit. However, an increase in fracturing within this unit probably would have no effect on flow unless major new faults develop that could act as flow pathways. The matrix hydraulic conductivity of the vitric Calico Hills unit generally is high enough for it to transmit all the flux that enters from the matrix of the overlying Topopah Spring welded unit. This is assuming the upper bound on current flux estimates of 0.5 millimeter (0.02 inch) per year (Wilson, 1985). For the zeolitic Calico Hills, fracture flow is likely to occur in portions

with saturated hydraulic conductivity values of about 0.5 millimeter (0.02 inch) per year and less.

Even in the saturated zone, fracture flow probably is not significant in the tuffaceous beds of Calico Hills. Observations in drill holes indicate that this unit is generally less fractured than welded tuffs in the section. In addition, hydraulic data for the tuffaceous beds of Calico Hills within the saturated zone at Well J-13 indicate that fracture permeability is 0.094 to 0.15 meters (3.7 to 5.9 inches) per day, which is moderate (Thordarson, 1983). At Well UE-25b#1, the unit is more permeable (Lahoud et al., 1984); this site is in Drill Hole Wash, where fractures not typical of most of Yucca Mountain could account for the higher permeability. In the units below the tuffaceous beds of Calico Hills, an increase in fracture frequency would have little effect on flow rates. Drill-hole data indicate that most of the flow occurs within fractures, which are already quite common in the moderately to densely welded tuffs. The resulting small increase in hydraulic conductivity probably would not be significant.

Potential changes in effective porosity due to tectonic movement probably would have a negligible effect on the transport of radionuclides to the accessible environment. In the saturated tuffs where fracture flow is dominant, a decrease in effective porosity would be accompanied by a larger decrease in hydraulic conductivity because effective porosity is a function of aperture size, whereas conductivity is a function of the square of the aperture size. In the unsaturated zone, an increase in effective porosity could occur as a result of fracture formation, which probably would increase the ability of the host rock to freely drain excess water, a favorable characteristic. In the saturated zone, effective porosity could increase by fracture formation or decrease by mineral precipitation. On the other hand, the effect of a decrease in effective porosity by precipitation of minerals in fractures may be offset by increased sorption due to fracture coatings that are often very reactive minerals (zeolites, smectites, and manganese oxides) and may increase retardation of radionuclides.

Conclusion

Substantial changes in geohydrologic conditions may result from possible changes in climatic conditions. Tectonic movements are expected to have minor effects on flow conditions. No changes in geohydrologic conditions are expected that would significantly increase the transport of radionuclides to the accessible environment as compared with pre-waste-emplacement conditions because retardation mechanisms are likely to remain effective. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(2) The presence of ground-water sources, suitable for crop irrigation or human consumption without treatment, along ground-water flow paths from the host rock to the accessible environment.

Evaluation

Ground-water sources suitable for human consumption are present along probable flow paths from the repository generally to the south or southeast

toward Jackass Flats and the Amargosa Desert (Waddell, 1982; Robison, 1984). Possible ground-water sources along those flow paths are defined in the guidelines as "aquifers that have been or could be economically and technologically developed as sources of water in the foreseeable future." Ground water withdrawn from the Yucca Mountain area, for example, from wells J-12 and J-13, has been used as drilling water for exploratory holes at and near the Nevada Test Site (NTS) and for other minor domestic uses on the NTS. The water extracted has not been used for irrigation.

Beneath Yucca Mountain, the water-resource potential is low compared with other areas in the vicinity of the NTS (Sinnock and Fernandez, 1982) because people do not normally drill for water from the top of a mountain, especially when the depth to the water table is much less in nearby valleys. On the flats on the east side of Yucca Mountain (Fortymile Wash and western Jackass Flats), the potential is considered to be higher. However, everywhere within the controlled area, the depth to water is more than 400 meters (1,300 feet) and pumping water for irrigation from such depths is likely to be uneconomical.

From the standpoint of the commercial value of ground water, irrigation is not of major concern in the site area primarily because of the poor characteristics of the alluvium, which make the site undesirable for agricultural use. The alluvium is coarse grained and drains rapidly except in the playa areas, where the concentration of salts makes it unlikely that crops could be grown. Pressure to develop ground water locally for human consumption is not likely, because land use is restricted. Even if extensive ground-water extraction caused the water table to be lowered, this would result in a thicker unsaturated zone, which would increase the travel time to the accessible environment.

Conclusion

Ground-water sources suitable for crop irrigation and human consumption are present at Yucca Mountain along ground-water flow paths between the host rock and the accessible environment. However, because of the great depths to ground water and topographic conditions, the ground-water resource potential is small compared with that in nearby areas, such as the Amargosa Desert. Nonetheless, the statement of the potentially adverse condition refers to the presence of ground water, not to the likelihood of its use. The evidence therefore indicates that this potentially adverse condition is present at Yucca Mountain.

(3) The presence in the geologic setting of stratigraphic or structural features--such as dikes, sills, faults, shear zones, folds, dissolution effects, or brine pockets--if their presence could significantly contribute to the difficulty of characterizing or modeling the geohydrologic system.

Evaluation

The available reports and conclusions about the general complexity of the Yucca Mountain area are discussed under favorable condition 3 of this section.

The geologic characteristics of the surface at Yucca Mountain are well known from detailed mapping (see Figure 6-20, in Section 6.3.1.7) (Scott and Bonk, 1984). Because of the numerous drill holes and interpretations of geophysical data, it is unlikely that major unrecognized features exist in the subsurface. Locations and displacements of normal faults can be estimated with reasonable certainty (Bath and Jahren, 1984). Zones with small displacement occur north of the primary repository area; the high hydraulic gradient in the area where they occur (Robison, 1984) indicates that the permeability along these zones is probably low, except for along the lower part of Drill Hole Wash. Many holes have been drilled in or near Drill Hole Wash to characterize the zone. Small basaltic dikes have been observed on the flank of Yucca Mountain northwest of the primary repository area; they may extend into the primary area and may produce the magnetic anomalies observed by Bath and Jahren (1984).

Conclusion

As a result of extensive field mapping and geophysical studies, faults, fracture zones, and dikes are known to exist at and near the Yucca Mountain site. These features will not prevent the formulation of conceptual models for the geohydrologic system. However, their presence contributes to the difficulty of characterizing and modeling the geohydrologic system. Therefore, the evidence indicates that this potentially adverse condition is present at Yucca Mountain.

6.3.1.1.5 Disqualifying condition

A site shall be disqualified if the pre-waste-emplacement ground-water travel time from the disturbed zone to the accessible environment is expected to be less than 1,000 years along any pathway of likely and significant radionuclide travel.

Evaluation

The time required for water to travel from the repository to the accessible environment depends on the hydraulic properties of the formations through which the water will flow, the hydrologic conditions, and the lengths of flow paths. The flow path of interest at Yucca Mountain includes segments in both the unsaturated and the saturated zones, as shown in the hydrogeologic section in Figure 6-2. The rocks at Yucca Mountain consist mainly of ash-flow tuff, bedded tuff, and lava that extend to depths greater than 1,829 meters (6,000 feet). Depths to the water table range from 500 to 750 meters (1,600 to 2,500 feet) below the land surface (Robison, 1984). Figure 6-3 consists of a map of the Yucca Mountain site, showing contours of water-table altitudes and drill-hole locations. A summary of key characteristics and properties of stratigraphic and hydrogeologic units at Yucca Mountain is shown in Table 6-17.

A portion of the precipitation that falls on Yucca Mountain infiltrates below the land surface to become net infiltration. Net infiltration is the infiltrating water that does not remain in shallow storage or is not rapidly returned to the atmosphere via evapotranspiration, but rather moves downward

Figure 6-2. Conceptual hydrogeologic section from Solitario Canyon, northwest of the site, to Well J-13 in Jackass Flats. The unsaturated zone is above the water table; the saturated zone is below the water table. Modified from Scott and Bonk (1984).

Figure 6-3. Water-table position at Yucca Mountain showing 20-meter contours of water-table altitude, location of drill holes, outlines of the primary repository area (dashed), and perimeter drift of the design repository (solid). Modified from Sinnock et al. (1986).

Table 6-17. Dual classification of Tertiary volcanic rocks at Yucca Mountain; stratigraphic units reflect origin and hydrogeologic units reflect hydrologic properties^a

STRATIGRAPHIC UNIT		TUFF LITHOLOGY ^b	HYDROGEOLOGIC UNIT ^c	SATURATED MATRIX HYDRAULIC CONDUCTIVITY	COMMENTS
Alluvium		---	Alluvium	Generally high	Underlies washes: thin layer on flats
Paintbrush Tuff	Tiva Canyon Member	MD	Tiva Canyon welded unit	1 mm/yr	Caprock that dips 5–10° eastward at Yucca Mountain. High fracture density.
	Yucca Mountain Member	NP, B	Paintbrush nonwelded unit	3300 mm/yr	Vitric, nonwelded, porous, poorly indurated, bedded in part. Low fracture density.
	Pah Canyon Member				
	Topopah Spring Member	MD	Topopah Spring welded unit	0.7 mm/yr ^d	Densely to moderately welded; several lithophysal cavity zones, intensely fractured. Central and lower part is potential host rock for repository. Bulk hydraulic conductivity in saturated zone east of the site (at well J–13) about 1.0 m/day.
Tuffaceous beds of Calico Hills		NP, B	Calico Hills nonwelded unit	Vitric: 107 mm/yr ^d	Beneath Yucca Mountain, base of units for unsaturated zone determined by water table. Calico Hills nonwelded unit is vitric in southwest Yucca Mountain, zeolitic in east and north. Zeolitic boundary generally parallels the water table with vitric units above and zeolitic units below a transitional boundary.
Crater Flat Tuff	Prow Pass Member	MD	PP _w	88 mm/yr ^d	
	Bullfrog Member	NP, B	PP _n	22 mm/yr ^d	
		MD	BF _w	118 mm/yr ^d	
	Tram Member	NP, B	BF _n	22 mm/yr ^d	
Lava		Undifferentiated		Very low	Occurs in northwest part of repository block.
Lithic Ridge Tuff				Very low	None
Older volcanics				Very low	In USW H–1 hydraulic head about 50 m higher than water table.
Pre-Tertiary Rocks				Unknown	Occurs 2.5 km east of proposed repository at depth of 1250 m in UE–25p#1, where hydraulic head is about 20 m higher than water table. Bulk hydraulic conductivity high, probably due to high fracture density

^aData from Montazer and Wilson (1984) except as indicated.

^bNP = nonwelded to partially welded; MD = moderately to densely welded; B = bedded.

^cHydrogeologic unit symbols: PP_w = Prow Pass welded unit; PP_n = Prow Pass nonwelded unit; BF_w = Bullfrog welded unit; BF_n = Bullfrog nonwelded unit.

^dData from Sandia National Laboratories Tuff Data Base (SNL, 1985).

into the deeper parts of the unsaturated zone. Flux at any depth, also referred to as percolation, is determined by the volume and the rate of net infiltration and by the hydraulic properties of rocks in the unsaturated zone. Upon reaching the water table beneath Yucca Mountain, percolating water becomes recharge and joins other ground water in transit from sources of recharge north or northwest of Yucca Mountain. The ground water then moves generally horizontally to the accessible environment, driven by a hydraulic gradient approximately equal to the slope of the water table and controlled by the hydraulic properties of the intervening rocks.

A discussion of the rationale used to derive a value for unsaturated zone flux at Yucca Mountain is presented below, followed by a description of the model that was used to calculate travel time in the unsaturated zone. This model uses a range of values for effective porosity and saturated matrix hydraulic conductivity to produce a distribution of travel times for a given value of flux. A final section provides the calculation of travel time in the saturated zone, so that the total travel time from the disturbed zone to the accessible environment can be determined.

Unsaturated zone flux

The flux needed for the travel-time calculations for this evaluation is the percolation rate (flux) between the disturbed zone and the water table. The primary repository area has a surface expression and also represents the outline of the conceptual repository at depth (Figure 6-3). The primary repository area occupies only a part of the physiographic feature called Yucca Mountain. The northern half and southern tip of Yucca Mountain and the fault zone that bounds the area along the eastern side are not a part of the primary repository area. Recharge beneath the primary repository area probably is less than recharge beneath Yucca Mountain as a whole. This difference occurs because (1) lateral flow probably occurs above the repository horizon and diverts some water beyond the repository area to be recharged along the eastern fault zone; and (2) much of the recharge at Yucca Mountain probably results from precipitation falling on parts of the mountain where altitudes are greater than those of the surface expression of the primary repository area. If these conditions exist, then the use of the estimate of recharge (0.5 millimeter (0.02 inch) per year) occurring beneath all of Yucca Mountain for unsaturated zone travel-time calculations beneath the primary repository area is a conservative approach (i.e., the calculated travel times would be shorter than those that would be predicted from a more realistic value of flux). In order to evaluate the appropriateness and degree of conservatism of this value, estimates and comparisons were made of various flux parameters at Yucca Mountain, using two approaches (Wilson, 1985).

The first approach to estimate deep flux within and below the repository was to analyze various lines of field and laboratory evidence (Wilson, 1985)³. Weeks and Wilson (1984) estimated a matrix flux of 0.2 millimeter (7.9×10^{-3} inch) per year in the Topopah Spring welded unit, using matrix properties of core. Montazer and Wilson (1984) estimate from 10^{-7} to 0.2 millimeter (3.9×10^{-9} to 7.9×10^{-3} inch) per year of flux could be occurring in the matrix of the Topopah Spring welded unit. This range of values is based principally on analyses of thermal flux, properties of cores, and in situ potential gradients. Montazer et al. (1985) indicate that an upper bound of

0.5 millimeters (0.02 inch) per year is consistent with the available information. Preliminary analyses of geothermal gradients indicate that an upward component of vapor flux probably exists in the fractures of the Topopah Spring welded unit (Montazer and Wilson, 1984; Montazer et al., 1985). Although no firm value for moisture flux in the Topopah Spring unit has yet been established, all preliminary field and laboratory estimates are less than 0.5 millimeter (0.02 inch) per year.

The second approach (Wilson, 1985) was to estimate ground-water recharge at Yucca Mountain by applying a technique developed by Maxey and Eakin (1949) and described further by Eakin et al. (1951). The technique provides a method for estimating ground-water recharge in basins in Nevada on the basis of relationships that were established among altitude, precipitation, and the percentage of precipitation that infiltrates to become recharge. The relationships were established by equating basin recharge to ground-water discharge for basins where this parameter could be estimated. For large areas, net infiltration and recharge can be considered to be approximately equivalent. Although infiltration occurs sporadically in an arid environment, such as exists at Yucca Mountain, average annual net infiltration probably is an appropriate input parameter for simulating flux conditions at the substantial depths of the repository horizon and below. As noted by Weeks and Wilson (1984), in unsaturated zones that are hundreds of meters thick, the large near-surface fluctuations in soil-moisture tension that result from episodic infiltration events followed by evapotranspiration become totally damped at depth, and deep percolation becomes nearly constant with time. According to the conceptual model for Yucca Mountain developed by Montazer and Wilson (1984), relatively large pulses of infiltrating water probably are transmitted through the Tiva Canyon welded unit but are damped in the Paintbrush nonwelded unit by means of lateral flow or changes in saturation, and are transmitted as steady-state flux through the potential host rock, the Topopah Spring welded unit.

The Eakin method was applied by Rush (1970) to estimate average annual recharge for basins in the Nevada Test Site area, including western Jackass Flats and Crater Flat. These basins have Yucca Mountain as a mutual boundary and include some areas where altitudes exceed 1,829 meters (6,000 feet). Rush (1970) estimated an average annual recharge of 1.4 millimeters (0.055 inch) per year for Jackass Flats and 0.6 millimeter (0.024 inch) per year for Crater Flat. Czarnecki (1985) applied Rush's (1970) results to a smaller area that included Yucca Mountain but excluded altitudes greater than 1,829 meters (6,000 feet). Czarnecki (1985) calculated a value of 0.7 millimeter (0.027 inch) per year for recharge beneath the smaller area; he adjusted this value to 0.5 millimeter (0.02 inch) per year. In Czarnecki's (1985) analysis, almost all of the recharge was derived from precipitation falling on an altitude zone that is about 305 meters (1,000 feet) higher, on the average, than that of the surface area above the repository (altitude 1,220 to 1,524 meters (4,000 to 5,000 feet)). Thus, only a small part of the 0.7 millimeter (0.027 inch) per year recharge would be expected to come from precipitation falling on the surface above the primary repository area. The value calculated by Czarnecki (1985) is probably greater than the actual value of ground-water recharge beneath the primary repository area at Yucca Mountain. The surface above the primary repository area is not transected by any major washes originating at higher altitudes that could transfer runoff

downstream to be recharged beneath the repository. Furthermore, the washes that extend downward from the ridges within the surface area above the repository may be effective in carrying runoff that might otherwise become recharge to locations beyond this area. This is apparent in that runoff from major precipitation events is periodically carried away by Fortymile Wash. Thus, considering the altitude zone of the surface of the primary repository area and the uncertainty in the Eakin method, recharge is probably less than 0.5 millimeter (0.02 inch) per year according to Czarnecki (1985).

Although the method described by Eakin et al. (1951) has been widely used to estimate ground-water recharge in basins in Nevada and Utah, the technique provides only an approximation of recharge, and it was not intended for site-specific application. Czarnecki (1985) described some of the limitations: local variations in topographic slope and aspect are ignored, rock lithology and vegetation type and density are only indirectly included, and drainage channels are treated the same as other areas. General hydrologic equilibrium is assumed to exist for the flow system, a condition that may not prevail where thick unsaturated zones and long flow paths may result in a substantial lag time between net infiltration, recharge, and discharge. Furthermore, the method does not specify where recharge occurs; runoff that crosses altitude zones can result in recharge in areas different from those where the precipitation fell. The result is that predicted values of recharge may be too small or too large, depending on whether runoff enters or leaves the area. Despite these limitations, Watson et al. (1976), in an evaluation of the method, concluded that it is the only practical method available for estimating recharge in Nevada from data that now exist.

An indirect test of the Maxey-Eakin method also confirms that the estimate of 0.5 millimeter (0.02 inch) per year for recharge at Yucca Mountain probably is both reasonable and conservative (Wilson, 1985). Recharge rates as a percentage of average annual precipitation for arid and semiarid areas worldwide were compared to recharge estimates obtained by applying the Maxey-Eakin method (Wilson, 1985). Although there are numerous sources of uncertainty in the recharge estimates, recharge rates for many of the areas are less than predicted by the Maxey-Eakin method. Especially significant are five areas where recharge is estimated to be less than 0.5 percent of precipitation. Each of these areas receives precipitation that is greater than the 150 millimeters (5.9 inches) per year at Yucca Mountain, and recharge as a percentage of precipitation varies from 0 to 0.12 percent. These worldwide data appear to support the conservatism of the recharge estimate of 0.3 percent of 150 millimeters (5.9 inches) per year, or 0.5 millimeter (0.02 inch) per year for Yucca Mountain. Field and laboratory investigations planned for site characterization are intended to provide further confidence in the estimate of recharge beneath the primary repository area at Yucca Mountain.

In conclusion, various lines of reasoning and evidence demonstrate that 0.5 millimeter (0.02 inch) per year is a conservative value of flux to use in calculating unsaturated zone pre-waste-emplacement travel time. Field and laboratory evidence and assessments of the precipitation-recharge relationship for the primary repository area indicate that the unsaturated zone flux below the repository horizon is less than 0.5 millimeter (0.02 inch) per year (Wilson, 1985). For this reason a value of 0.5 millimeter (0.02 inch) per year is used in the calculations of ground-water travel time and in several

other calculations reported in this environmental assessment. It is considered to represent the upper bound to the estimated range of current flux below the repository horizon. Investigations conducted during site characterization will further define unsaturated zone flux.

Calculation of unsaturated zone travel times

Because the thicknesses and hydraulic properties of the hydrogeologic units that make up the unsaturated zone at Yucca Mountain are variable, an approach was developed to take this variability into account in calculation of travel times (Sinnock et al., 1986). The disturbed zone was assumed to extend to a position 50 meters (164 feet) below the midplane of the repository. A projection of the perimeter drift of the design repository (see Figure 6-3) on the surface of the disturbed zone was divided into 963 columns, extending to the water table. Total unsaturated zone thickness and the thicknesses of hydrogeologic units between the disturbed zone and the water table are shown in Figure 6-4. The travel time to the water table through each of the 963 vertical columns was determined. The total travel-time distribution for a given value of moisture flux will be presented as a contour map, a histogram, and a cumulative-frequency diagram of travel times. Table 6-18 shows the values for hydraulic parameters used for these calculations, including means and standard deviations for effective porosity and saturated matrix hydraulic conductivity for the seven hydrogeologic units considered in this calculation.

As summarized above, the three-dimensional volume of each hydrogeologic unit beneath the repository area was subdivided into 963, 76.2-meter (250-foot) square vertical columns, with each column enclosing 5,806 square meters (62,500 square feet) (Sinnock et al., 1986). Each column was divided into 3.05-meter (10-foot) thick elements, giving a three-dimensional grid of the site composed of 80,521 elements, 10 feet thick and 250 feet on each side. See Figure 6-5 for a schematic drawing of the columns and elements used in the model. The particle velocity for each element within a particular hydrogeologic unit was calculated by using a value of saturated matrix hydraulic conductivity that was obtained by standard statistical sampling methods from the frequency distribution that best describes the conductivity data for that particular unit. This randomly selected value of conductivity was compared with the value of flux. If the flux value was less than 0.95 times the saturated matrix hydraulic conductivity, it was assumed that the flow within that element was entirely in the porous rock matrix, and a value of matrix effective porosity was then chosen by random sampling from the frequency distribution of porosity values for the appropriate hydrogeologic unit. The water particle velocity for each element was then calculated by dividing the flux value by the sampled effective porosity, assuming a hydraulic gradient equal to 1.0. The velocity was modified, according to concepts explained by Brooks and Corey (1966), to account for the relation between effective flow area and saturation (see Table 6-18 for the formula used to calculate particle velocities).

The value of 0.95 was used for the comparison of the flux value with saturated conductivity to account for potential initiation of fracture flow at saturations less than 100 percent (Sinnock et al., 1986). If the ratio of flux to the randomly sampled value of saturated matrix hydraulic conductivity was equal to or greater than 0.95, it was assumed that fracture flow occurred

Figure 6-4. Isopach contour maps: (A) Total thickness from disturbed zone to the water table; (B) Thickness of undisturbed Topopah Spring welded unit, TS_w; (C) Thickness of the Calico Hills vitric unit, CH_v; (D) Thickness of the Calico Hills zeolitic unit, CH_z; (E) Thickness of the Prow Pass welded unit, PP_w; (F) Thickness of the Prow Pass nonwelded unit, PP_n; (G) Thickness of the Bullfrog welded unit, BF_w; and (H) Thickness of the Bullfrog nonwelded unit, BF_n. Modified from Sinnock et al. (1986).

Table 6-18. Parameters used in travel-time calculations for the unsaturated zone

Hydrogeologic unit ^a Parameter	TS _w	CH _{n-v}	CH _{n-z}	PP _w	PP _n	BF _w	BF _n ^b	Remarks
Hydraulic gradient (i)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	$i = \partial h / \partial l = \partial \psi / \partial l + \partial z / \partial l$ where $l = x, y, z$, $\partial \psi / \partial l \ll 1.0$ and $\partial z / \partial l = \partial z / \partial z = 1.0$, i.e. vertical gravity flow is assumed.
Mean saturated-matrix hydraulic conductivity K_s (mm/yr) ^c	0.7 (31)	107 (8)	0.5 (31)	88 (10)	22 (7)	118 (2)	22 (NA)	$\bar{K}_s = \ln^{-1}(\text{mean}[\ln(K_s)])$ Values in parentheses are the number of measurements.
$K_s - 1\sigma$ (mm/yr)	0.1	1.9	0.0	29	3	58	3	$\pm 1\sigma(K_s) = \bar{K}_s + \ln^{-1}(\ln \sigma[K_s])$
$\bar{K}_s + 1\sigma$ (mm/yr)	4.1	6,090	7.6	261	142	240	142	
Mean Effective Porosity $\bar{n}_e \pm 1\sigma$	0.11 $\pm .05$ (138, 12)	0.32 $\pm .09$ (23, 6)	0.27 $\pm .05$ (65, 10)	0.24 $\pm .06$ (27, 4)	0.25 $\pm .06$ (75, 2)	0.22 $\pm .09$ (120, 2)	0.25 $\pm .06$ (NA)	$\bar{n}_e = n_b(1-S_r)$, where n_b is the mean bulk, dry porosity and S_r is residual saturation. Ordered pairs in parentheses are number of measurements of n_b and S_r , respectively.
Range of thicknesses (m) ^d	0-72 (98.5)	0-135 (95.3)	0-133 (94.5)	0-44 (83.2)	0-122 (63.1)	0-91 (25.6)	0-55 (7.5)	Thicknesses between disturbed zone and water table for area within the design repository boundaries. Values in parentheses are percentages of total repository are underlain by the units.
Particle velocity, V (mm/yr)	$q = 0.5$ mm/yr	5.0	5.5	1.9	7.6	4.1	7.3	$V = (q/n_e)(q/K_s)^{-1/\epsilon}$, where n_e and K_s are mean values and q is flux. Values in parentheses indicate fracture-flow velocity calculated as $(q-K_s)/0.0001$, where 0.0001 is the assumed effective porosity of fractures.
	$q = 1.0$ mm/yr	8.9 (2,780)	9.4	3.4 (4,650)	12.8	7.2	12.5	
ϵ^e	5.9	4.2	7.0	4.0	5.2	4.6	5.2	Empirical constant that represents the effects of the relationship between pore-size distribution and saturation on the amount of the effective porosity, n_e , available for flow; the effect of ϵ is to reduce flow area and thus increase particle velocity relative to values calculated using q/n_e .

^aTS_w = Topopah Spring welded unit; CH_{n-v} = Calico Hills vitric unit; CH_{n-z} = Calico Hills zeolitic unit; PP_w = Prow Pass welded unit; PP_n = Prow Pass nonwelded unit; BF_w = Bullfrog welded unit; BF_n = Bullfrog nonwelded unit.

^bAssumed to be hydrologically identical to PP_n.

^cSaturated conductivity and effective-porosity data are from Sandia National Laboratories Tuff Data Base (SNL, 1985).

^dRange of thickness, Sandia National Laboratories Interactive Graphics Information System (IGIS) (SNL, 1985).

^eValues calculated from data in Peters et al. (1984).

Figure 6-5. Schematic diagram illustrating three-dimensional geometry for multiple elements 10 feet thick. In Method 2, only 1 element is assigned to each unit and its thickness equals the unit thickness. Modified from Sinnock et al. (1986).

Figure 6-6. Travel-time contour map from disturbed zone to water table. Modified from Sinnock et al. (1986).

for that quantity of flux in excess of the value of saturated matrix conductivity (or in excess of 0.95 times conductivity when the ratio of flux to hydraulic conductivity is between 1.0 and 0.95). An effective porosity of 0.0001 was assumed for all fracture flow, and the velocity of flow in fractures for each element was determined by dividing the calculated value of flux in the fractures by 0.0001. The portion of flux remaining in the matrix was used to obtain a matrix-flow time as well as a fracture-flow time for each element characterized by fracture flow. Matrix-flow times for these dual porosity elements were usually greater than the fracture-flow times; however, the shorter of matrix or fracture flow time was used to generate the travel-time distribution through these elements.

This procedure was repeated for each 10-foot thick element within each of the 963 vertical columns for each hydrogeologic unit occurring between the disturbed zone and the water table (Sinnock et al., 1986). The sum of all individual-element travel times represents a value of travel time along one column. This procedure was repeated 10 times for each column to provide a representation of the variation in travel time due to the variation in hydraulic parameters. Reflecting the varying thicknesses shown in figures 6-4(B) through 6-4(H), each column is composed of differing thicknesses of the various unsaturated zone hydrogeologic units. These differences produce a source of variation in travel time in addition to the variation caused by random sampling of parameters. It was determined that differences in thickness of hydrogeologic units have a greater influence on the modeled travel times than the variations due to use of randomly selected values for hydraulic parameters.

Results for the upper bound on estimated flux of 0.5 millimeter (0.02 inch) per year are shown in figures 6-6 and 6-7. Figure 6-6 shows smoothed contours of travel time in 5,000-year intervals from the disturbed zone to the water table. This travel-time contour map clearly shows a gradient from the shorter travel times of less than 20,000 years on the east, to travel times greater than 60,000 years on the south. Note that this pattern correlates well with the thicknesses of major hydrogeologic units shown in figures 6-4(B) through 6-4(H). Figure 6-7 shows a histogram of travel times for the 10 realizations for each of the 963 columns. Cumulative-frequency curves are also provided in Figure 6-7 illustrating how travel times within each hydrogeologic unit contribute to the distribution of total travel times. The minimum travel time is estimated to be 9,345 years, with a mean travel time of 43,265 years and a maximum of 80,095 years (Sinnock et al., 1986). It should be noted that minimum and maximum travel-time values cannot be observed on the histogram because of the intervals used to construct the histogram. However, the above values were obtained from the output used to plot the histogram.

Several major assumptions underlie the calculations presented in this section. The first assumption is that unsaturated zone flux below the disturbed zone is vertical and uniformly distributed in time and space (i.e., the unsaturated zone at Yucca Mountain is assumed to have a vertical hydraulic gradient determined solely by gravity). The hydrologic properties of the rocks above the repository are probably able to dampen episodic infiltration so that nearly steady-state flow occurs between the repository and the water table. An assumption of a vertical hydraulic gradient of unity is probably conservative because the occurrence of lateral flow would reduce

Figure 6-7. Travel-time plots: (A) Travel-time histogram for 9,630 realizations of travel-time model; flux = 0.5 millimeter (0.02 inch) per year; element thickness = 10 feet; (B) Cumulative frequency of travel times for 9,630 realizations (normalized to a scale of 0.0 to 1.0). Modified from Sinnock et al. (1986).

this value to less than one, thereby decreasing the particle velocity. Only in the case of diversion to a zone of higher permeability would this assumption be nonconservative.

A second major assumption is that the effective hydraulic conductivity through the matrix of any given rock volume delicately adjusts by changes in saturation so that the effective conductivity exactly equals the flux. This assumption is particularly important where the value of conductivity is less than the flux. In these cases, the matrix is assumed to conduct water up to an amount equal to the saturated conductivity, while the remainder of the flux travels in fractures. If the flux is less than the saturated conductivity for a particular interval, the relations among pore sizes, saturations, and capillary pressures are assumed to adjust to yield an effective conductivity just sufficient to pass the flux under a gravity-controlled gradient.

A third assumption underlying these calculations is that, at certain conditions of saturation, water probably does not move rapidly through fractures until flux approaches the saturated matrix hydraulic conductivity. Concepts from other authors reviewed in Sinnock et al. (1984) support this assumption. These references indicate that negative capillary pressures exerted by the pores of the matrix are sufficiently strong to rapidly draw water away from fractures (where pressures are much less negative) even when the matrix is nearly saturated. This capillary-driven advection probably precludes significant, sustainable fracture flow where the conductivity is less than the flux within the unsaturated tuffs beneath the repository. Some flow may take place in thin layers along the walls of fractures under unsaturated conditions. Such flow would, however, be likely to have the same properties as flow in the matrix (Montazer and Wilson, 1984).

All evidence indicates that flux is less than 0.5 millimeter (0.02 inch) per year (Wilson, 1985). Nevertheless, travel time was also calculated for a flux of 1.0 millimeter (0.04 inch) per year, or twice the upper bound flux of 0.5 millimeter per year (0.02 inch per year) (Sinnock et al., 1986). A total travel-time histogram is shown in Figure 6-8. Even for this unrealistically conservative estimate of flux, the data plotted on this histogram show a minimum travel time in the unsaturated zone of at least 3,700 years, a mean travel time of 21,045 years, and a maximum of 45,190 years. Results of these calculations provide confidence that the 1,000-year travel time required by the disqualifying condition would be satisfied even with a flux that is much larger than expected.

In these calculations, the values of conductivity and the method of sampling result in a low probability that fracture flow will be identified for all vertical elements in a single column from the disturbed zone to the water table. Similarly, both rapid and very slow matrix flow, calculated from random sampling of effective porosity, are extremely unlikely to occur throughout a vertical column. To examine sampling effects that may be due simply to the sampling method, an alternative approach, shown as Method 2 in Figure 6-5, was implemented whereby one value of conductivity and effective porosity chosen by random sampling was used for the entire thickness of each hydrogeologic unit (Sinnock et al., 1986). To generate probabilities of flow times, the sampling was repeated 100 times for each column. This approach yields higher, but probably physically unrealistic, estimates of the

Figure 6-8. Travel-time histogram for 9,630 realizations of the travel-time model; flux = 1.0 millimeter (0.04 inch) per year; element thickness = 10 feet. Modified from Sinnock et al. (1986).

probability of continuous fracture flow and rapid matrix flow than the 10-foot interval sampling method described above, which more realistically accounts for vertical as well as horizontal variation in the sampling parameters.

The cumulative frequency curves generated by the two sampling methods for a flux of 0.5 millimeter (0.02 inch) per year are compared in Figure 6-9. Although the overly conservative method (i.e., Method 2: single value per hydrogeologic unit) predicts travel times of less than 1,000 years for the 0.5 millimeter (0.02 inch) flux value, this probability is less than 2 percent (Sinnock et al., 1986). The results from this highly conservative modeling approach are included to indicate the potential effect of variations in hydrologic parameters in the vertical direction and to acknowledge travel times that could occur in the highly improbable situation in which fracture flow was sustained throughout an entire hydrogeologic unit.

Comparison of methods 1 and 2 (Figure 6-9) also shows that as more physical realism is introduced into the travel-time model, the range of travel times is likely to be compressed. Moving from Method 2 to Method 1 clearly had the effect of removing the low-probability, extreme values in the tails of the frequency distribution of travel times from the disturbed zone to the water table.

Calculation of saturated zone travel time

For the saturated zone, the assumed flow path extends from the eastern edge of the primary repository area southeastward (see Section 3.3.2.1) for 5 kilometers (3 miles) to the accessible environment (Figure 6-3). Approximately 80 percent of this path (4 kilometers (2.4 miles)) is in the tuffaceous beds of the Calico Hills, and the remainder of the flow path (1 kilometer (0.6 mile)) would be through the welded Topopah Spring Member or the welded Crater Flat Tuff (Prow Pass or Bullfrog member). Estimates for ground-water travel times along this travel path have been made using the following assumptions:

1. Darcian flow applies.
2. Flow paths are horizontal.
3. The water-level measurements shown in Figure 6-3 (based on Robison, 1984) provide a reasonable estimate for the hydraulic gradient along the flow path.
4. The system is isotropic within each unit, and hydraulic conductivity values obtained from hydraulic tests of wells in the southeastern Yucca Mountain area are representative of the values along the flow path.
5. Calculated effective fracture porosities from Sinnock et al. (1984) are reasonably conservative for flow in the saturated tuffaceous beds of the Calico Hills.

The average saturated hydraulic conductivity for the Calico Hills has been estimated to be 69 meters (230 feet) per year on the basis of values of

Figure 6-9. Cumulative frequency of travel times: Method 1--more realistic case; Method 2--more conservative, probably unrealistic, case. Flux is 0.5 millimeter (0.02 inch) per year for both cases. Modified from Sinnock et al. (1986).

0.26 meter (0.85 foot) per day from pumping tests in Well UE-25b#1 (Lahoud et al., 1984) and 0.12 meter (0.4 foot) per day from Well J-13 (Thordarson, 1983). The saturated hydraulic conductivity for the Topopah Spring Member is estimated to be 365 meters (1,198 feet) per year on the basis of 1.0 meter (3.28 feet) per day from Well J-13 (Thordarson, 1983).

On the basis of these assumptions, the hydraulic gradient has been estimated using water-level altitudes of 730.1 meters (2,395.3 feet) at USW H-4 and 728.1 meters (2,388.8 feet) at Well J-13 (Robison, 1984). The distance between these wells is approximately 6.1 kilometers (3.8 miles). The hydraulic gradient within each of the two units has been estimated from the two water-level altitudes, the two hydraulic conductivity values used, and the property of mass conservation, which requires that the amount of water flowing through the Calico Hills unit is the same as that flowing through the Tonopah Spring unit. Uncertainties in these estimates of hydraulic gradient include the following components: with very low gradients, small errors in the measurements can have significant effects on the value of the gradient; the measured water level at Well J-13 could be expected to be lower than the static water level because of pumping, thereby resulting in a steeper estimated gradient; and vertical components of flow may be present. Because vertical flow would have the effect of lengthening the flowpath, the assumption of horizontal flow is probably conservative, although Waddell et al. (1984) indicate that the controls on vertical and horizontal flow at Yucca Mountain are variable and generally unknown.

Table 6-19 shows these values and provides estimates for travel times through the two units mentioned above. On the basis of these estimates, the cumulative travel time through the saturated zone is about 141 years.

This estimate of travel time is considered to be conservative, based on the assumptions mentioned above and on the fracture effective porosities reported by Sinnock et al. (1984). These effective porosities were calculated by multiplying the fracture density from Scott et al. (1983) by the effective aperture (calculated from a relationship provided by Freeze and Cherry, 1979). The resulting effective porosities are considered to be reasonable estimates for fracture flow in the saturated zone. However, estimates of saturated effective porosity for both matrix and fracture flow range from 8 to 12 percent (Sinnock et al., 1984); 2.7 to 8.7 percent for the Topopah Spring Member (Thordarson, 1983); and 20 to 30 percent for the Calico Hills vitric unit (Sinnock et al., 1984). These effective porosities are more representative of the hydraulic conductivities indicated in Table 6-19, and in particular of the water-bearing nature of the Topopah Spring Member in the vicinity of Well J-13 (Thordarson, 1983). Use of more realistic values of effective porosity would be likely to lead to a saturated ground-water travel time at least ten times greater (i.e., approximately 1,000 years) than that indicated in Table 6-19. However, as no data exist to indicate that matrix flow predominates over fracture flow, the effective porosity used in this analysis assumes fracture flow in order to provide a conservative travel-time estimate.

Summary of travel times

A summary of total travel times is provided in Table 6-20 for the upper bound on flux of 0.5 millimeter (0.02 inch) per year. Adding the saturated

Table 6-19. Estimates for ground-water travel times through the saturated zone

Parameter	Unit	
	Calico Hills	Topopah Spring
Length of path (m) ^a	4,000	1,000
Hydraulic conductivity (m/yr) ^b	69	365
Hydraulic gradient ^c	4.6×10^{-4}	8.6×10^{-5}
Darcy velocity (m/yr) ^d	3.2×10^{-2}	3.1×10^{-2}
Calculated effective fracture porosity ^e	4×10^{-4}	2.8×10^{-3}
Particle velocity (m/yr) ^f	80	11
Travel time (yr) ^g	50	91

^a 1 meter (m) = 3.281 feet

^b Hydraulic conductivity for Calico Hills from Lahoud et al. (1984) and Thordarson (1983); Topopah Spring from Thordarson (1983).

^c Based on water levels at wells USW H-4 and J-13 and conservation of mass.

^d Darcy velocity = (hydraulic conductivity) x (hydraulic gradient).

^e Data from Sinnock et al. (1984).

^f Particle velocity = (Darcy velocity)/(bulk effective porosity).

^g Travel time = (length of path)/(particle velocity).

zone travel time of about 140 years to the minimum, mean, and maximum unsaturated zone travel times produces total minimum, mean, and maximum travel times of about 9,485; 43,405; and 80,235 years.

Conclusion

Using an upper bound on the estimated unsaturated zone flux and a range of values for saturated hydraulic conductivity and effective porosity at the Yucca Mountain site, estimates of the expected pre-waste-emplacement ground-water travel time along any path of likely and significant radionuclide travel from the disturbed zone to the accessible environment are more than 1,000 years. Therefore, the evidence does not support a finding that the site is disqualified (level 1).

Table 6-20. Summary of total travel time for upper bound flux of 0.5 millimeter per year

Travel paths	Travel times (years)
Unsaturated zone	
Minimum	9,345
Mean	43,265
Maximum	80,095
Saturated zone	
Calico Hills segment	50
Topopah Spring segment	91
Total travel time ^a	
Minimum	9,485
Mean	43,405
Maximum	80,235

^aTotal travel time is the total saturated zone travel time (rounded to the nearest 10 years) added to the minimum, mean, and maximum unsaturated zone travel time.

6.3.1.1.6 Evaluation and conclusion for the qualifying condition on the postclosure geohydrology guideline

Evaluation

The evaluation of the geohydrology disqualifying condition in the previous section shows that the ground-water travel time from the disturbed zone to the accessible environment for the upper bound on flux of 0.5 millimeter (0.02 inch) per year has a mean value of about 43,405 years, with a range of values from 9,485 years to 80,235 years.

Climatic changes during the Quaternary Period may have caused cyclic fluctuations in precipitation, infiltration, recharge, and water-table altitude beneath Yucca Mountain. Analyses presented in Section 6.3.1.2.3 establish the potential effectiveness of matrix diffusion as an agent for delaying the release of radionuclides to the accessible environment by factors of at least 100 and perhaps as much as 400. On the basis of these estimated retardation factors, Section 6.3.1.4.4 presents a discussion of the potential effects of climatic changes on radionuclide releases from a repository at the Yucca Mountain site. Considering conservative retardation factors and the maximum water-table rise that has been simulated for full pluvial conditions, radionuclide travel times from the repository to the accessible environment are expected to remain sufficiently long so that release limits could not be exceeded.

Although the Yucca Mountain site is considered complex from the standpoint of geologic structure and characterization of the unsaturated zone, methods are available to obtain all the information necessary for prediction of long-term site performance with reasonable certainty. Preliminary predictions of performance are available in the geochemistry and performance assessment sections of this environmental assessment. In favorable condition 4 in Section 6.3.1.2, both an experimental and a modeling approach are presented for estimating radionuclide releases from the engineered barrier system (EBS). For flux estimates that are twice the upper bound of 0.5 millimeter (0.02 inch) per year, releases estimated by either method are well within the EBS release limits of 1 part in 100,000 per year of the 1,000 year inventory. Section 6.4.2 presents preliminary estimates of cumulative radioactivity released to the accessible environment at 10,000 and 100,000 years after repository closure for a 0.5 millimeter (0.02 inch) per year flux. All cumulative radioactivity release values at 100,000 years after closure are below the cumulative releases permitted for 10,000 years after closure in 40 CFR Part 191 (1985), and cumulative releases at 10,000 years are essentially zero.

Conclusion

Quantitative analyses show that the expected radionuclide releases from the engineered barrier are less than 1 part in 100,000 (Section 6.3.1.2); they also show that the expected releases to the water table over the next 10,000 years would be essentially zero (Section 6.4.2). Analyses of ground-water flow time, ground-water flux, and radionuclide retardation further support the position that the characteristics of the Yucca Mountain site and the processes operating there permit, and probably ensure, compliance with the limits on radionuclide release to the accessible environment. Therefore, the evidence does not support a finding that the site is not likely to meet the qualifying condition for geohydrology (level 3).

6.3.1.1.7 Plans for site characterization

Various hydrologic tests are planned during site characterization, including tests during the construction and in situ phases of the exploratory shaft program at Yucca Mountain. Radial boreholes from the shaft will be used to determine vertical permeability and to evaluate the extent of mining-induced changes in vertical permeability near the shaft. Vertical flux and flux mechanisms, particularly across the boundaries of hydrogeologic units, will be evaluated by injection tests and continuous monitoring in boreholes. Samples of pore water will be dated and used to help evaluate the flow velocities and travel times through various units. Thermal logs will be used as another means for estimating the vertical movement of water in the unsaturated zone, which is important for confirming estimates of flux and travel times.

A bulk-permeability test will be conducted during the in situ phase of testing to establish the hydrologic characteristics of a larger volume of the host rock than can be sampled from a borehole. The results of this test will improve hydrologic models and allow comparisons with borehole and laboratory-scale measurements. Also planned is an infiltration test, designed to obtain

the hydraulic properties of the host rock, including permeability and flow characteristics, and to provide data for curves of hydraulic conductivity versus the matric potential.

Hydrologic testing of the unsaturated Calico Hills nonwelded unit, which underlies the host rock, is also planned. Determination of the transport properties and barrier characteristics of this unit will be extremely important in establishing its capacity for the retardation of radionuclides. Borehole testing of the saturated zone will be conducted to assist in evaluating conceptual models of ground-water flow and to determine probable flow paths and flow properties.

6.3.1.2 Geochemistry (10 CFR 960.4-2-2)

6.3.1.2.1 Introduction

The qualifying condition for this guideline is as follows:

The present and expected geochemical characteristics of a site shall be compatible with waste containment and isolation. Considering the likely chemical interactions among radionuclides, the host rock, and the ground water, the characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.

The geochemistry technical guideline addresses the present and expected geochemical characteristics of the proposed Yucca Mountain site and provides the basis for demonstrating compatibility with performance objectives for waste containment and isolation as specified in the Nuclear Regulatory Commission and the U.S. Environmental Protection Agency technical criteria.

This guideline contains five favorable conditions, three potentially adverse conditions, and one qualifying condition. The evaluations reported below are summarized in Table 6-21.

6.3.1.2.2 Data relevant to the evaluation

Summary of available data

The mineral content, mineral composition, and petrographic texture of the rocks at and near Yucca Mountain have been determined from drill-core rock samples and bit cuttings (Heiken and Bevier, 1979; Sykes et al., 1979; Carroll et al., 1981; Bish et al., 1982; Caporuscio et al., 1982; Bryant and Vaniman, 1984; Levy, 1984a; and Vaniman et al., 1984). The mechanism and

Table 6-21. Summary of analyses for Section 6.3.1.2; geochemistry (10 CFR 960.4-2-2)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITIONS	
(1) The nature and rates of the geochemical processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years.	The evidence indicates that this favorable condition is present at Yucca Mountain: sorptive minerals (zeolites) were present in the tuff at Yucca Mountain throughout the Quaternary time; they are still present and are expected to contribute to isolation over the next 100,000 years.
(2) Geochemical conditions that promote the precipitation, diffusion into the rock matrix, or sorption of radionuclides; inhibit the formation of particulates, colloids, inorganic complexes, or organic complexes that increase the mobility of radionuclides; or inhibit the transport of radionuclides by particulates, colloids, or complexes.	The evidence indicates that this favorable condition is present at Yucca Mountain: geochemical properties are expected to promote matrix diffusion; zeolites along flow paths will sorb radionuclides; organic complexes that would increase radionuclide mobility are not present; particulates and colloids may be filtered by tuffs, thereby inhibiting transport.
(3) Mineral assemblages that, when subjected to expected repository conditions, would remain unaltered or would alter to mineral assemblages with equal or increased capability to retard radionuclide transport.	The evidence indicates that this favorable condition is present at Yucca Mountain: the radionuclide-retardation capacity of tuffs is not expected to degrade because of repository conditions.
(4) A combination of expected geochemical conditions and a volumetric flow rate of water in the host rock that would allow less than 0.001 percent per year of the total radionuclide inventory in the repository at 1,000 years to be dissolved.	The evidence indicates that this favorable condition is present at Yucca Mountain: expected geochemical conditions and vertical flux of less than 0.5 millimeter (0.02 inch) per year are expected to limit release to less than 0.001 percent per year of total radionuclide inventory at 1,000 years after permanent closure.

Table 6-21. Summary of analyses for Section 6.3.1.2; geochemistry (10 CFR 960.4-2-2) (continued)

Condition	Department of Energy (DOE) finding
(5) Any combination of geochemical and physical retardation processes that would decrease the predicted peak cumulative releases of radionuclides to the accessible environment by a factor of 10 as compared to those predicted on the basis of ground-water travel time without such retardation.	The evidence indicates that this favorable condition is present at Yucca Mountain: chemical adsorption, low flux, and matrix diffusion are expected to limit radionuclide release by at least a factor of 10.
POTENTIALLY ADVERSE CONDITIONS	
(1) Ground-water conditions in the host rock that could affect the solubility or the chemical reactivity of the engineered barrier system to the extent that expected repository performance could be compromised.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: the stainless steel waste disposal container and waste forms are not expected to show detrimental effects due to host-rock water chemistry.
(2) Geochemical processes or conditions that could reduce the sorption of radionuclides or degrade the rock strength.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: sorptive zeolites are metastable, but little reaction is expected in the next 100,000 years. Geochemical processes are too slow to affect repository performance through degradation of rock strength.
(3) Pre-waste-emplacement ground-water conditions in the host rock that are chemically oxidizing.	The evidence indicates that this potentially adverse condition is present at Yucca Mountain: water is expected to contain dissolved oxygen and be chemically oxidizing.

Table 6-21. Summary of analyses for Section 6.3.1.2; geochemistry (10 CFR 960.4-2-2) (continued)

Condition :	Department of Energy (DOE) finding
QUALIFYING CONDITION	
<p>The present and expected geochemical characteristics of a site shall be compatible with waste containment and isolation. Considering the likely chemical interactions among radionuclides, the host rock, and the ground water, the characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.</p>	<p>Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): releases to accessible environment are expected to be nearly zero for 10,000 years; unsaturated emplacement zone has benign chemistry and extremely low water flux, which are expected to aid engineered barrier performance.</p>

history of zeolitization of the tuffs has also been studied (Hoover, 1968; Bryant and Vaniman, 1984; Levy 1984b; Dibble and Tiller, 1981; Waters and Carroll, 1981; Hay, 1978). The potential host rock at Yucca Mountain, a zone of devitrified tuff in the Topopah Spring Member, is composed of approximately 98 percent quartz, feldspar, and cristobalite, with lesser amounts of zeolites and clays (Daniels et al., 1982).

The concentrations (Croff and Alexander, 1980) and equilibrium chemical behavior of the radionuclides present in the waste is still under active study. However, enough is known to predict the general behavior of most elements (Apps et al., 1983; Allard, 1982). The solubilities of waste elements in representative water from Yucca Mountain under oxidizing conditions, and in similar waters have been calculated by equilibrium thermodynamic methods (Allard, 1982; Duffy and Ogard, 1982; Wolfsberg et al., 1982; Apps et al., 1983; Means et al., 1983). Experiments to determine dissolution rates of spent fuel and borosilicate glass are under way (Oversby, 1983; Bates and Gerding, 1985a,b; Bazan and Rego, 1984; Eklund and Forsyth, 1978; Bibler et al., 1984; Wilson and Oversby, 1985; Johnson et al., 1981).

The sorption ratios, R_d , (also known as the distribution coefficient) of many radionuclides have been measured by batch sorption techniques for more than 40 tuff samples from 9 different tuff units (Ogard et al., 1983a,b; Wolfsberg et al., 1983; Bryant and Vaniman, 1984). Rundberg (1985) indicates that the sorption ratios obtained by batch sorption techniques are in good agreement with sorption ratios obtained on intact tuff for simple cations. Methods for estimating geochemical retardation by the calculation of retardation factors that are based on sorption ratios have been developed (Sherwood et al., 1975). The temperatures expected in the repository have been calculated (Johnstone et al., 1984; Travis et al., 1984; Morales, 1985). The location of the sorbing minerals in Yucca Mountain is largely determined (Bish et al., 1984; Vaniman et al., 1984; Bish and Vaniman, 1985), though stratigraphic details remain to be resolved. The stability of the sorbing minerals is less certain (Bish and Semarge, 1982; Smyth, 1982), but information on some reactions is available (Smyth, 1982). Retardation factors in Yucca Mountain tuffs have been estimated (Travis et al., 1984; Sinnock et al., 1984).

The flux of water through the unsaturated zone at Yucca Mountain has been estimated from several lines of evidence (Section 6.3.1.1.5). Water from wells in the vicinity of Yucca Mountain has been analyzed, and species naturally present in the water can be estimated (Benson et al., 1983; Daniels et al., 1983). The dissolved oxygen content of water in the unsaturated zone has been calculated (Linke, 1965) and the solubility of spent fuel in an oxidizing environment estimated (Lemire and Tremaine, 1980). Little quantitative information is available about the formation of colloids or the particulate content of water from the vicinity of Yucca Mountain (Rai and Swanson, 1981; Newton and Rundberg, 1984; Avogadro et al., 1982; Avogadro and DeMarsily, 1984; Kim et al., 1984; Olofsson et al., 1984). The potential for matrix diffusion to retard radionuclides in fractured rock with a low matrix permeability has been studied (Neretnieks, 1980). The porosity of tuffs at Yucca Mountain (Johnstone and Wolfsberg, 1980) and the effective diffusivities of tuffs from Yucca Mountain and Rainier Mesa (Walter, 1982; Daniels et al., 1983) have been measured.

Reactions of Topopah Spring tuff with Well J-13 water at 90 and 150°C (194 and 302°F) have been experimentally determined (Knauss et al., 1984; Oversby and Knauss, 1983). Data on the laboratory synthesis of some of the minerals in the tuff are available (Hawkins, 1981; Chi and Sand, 1983) and can be supplemented by the results of hydrothermal experiments (Wolfsberg et al., 1983; Allen et al., 1984) and thermodynamic calculations (Daniels et al., 1983). The corrosion of the reference waste disposal container material (austenitic stainless steel) in the expected repository environment has been studied (McCright et al., 1983; Oversby, 1985).

Assumptions and data uncertainties

Indirect methods have been used to estimate the initiation and duration of geochemical processes resulting in the alteration of minerals (Bryant and Vaniman, 1984) because techniques for the direct age dating of alteration products at the Yucca Mountain site have not been fully developed. Clinoptilolite and mordenite now present in Yucca Mountain are assumed to have been there for at least 10 million years. A temperature increase up to 85°C (185°F) total should not produce significant reaction of clinoptilolite to other minerals (Smyth, 1982).

For discussions about precipitation and complex formation of waste elements, equilibrium chemical behavior is assumed. Discussions about colloid formation are based on empirical observations. For sorption, the minerals present in the rock when it is crushed include altered minerals typically found in fracture fillings. These minerals are assumed to be more sorptive than the typical matrix minerals. Estimates of retardation factors are based on the assumption of equilibrium conditions.

Because there is uncertainty in the flux and flow mechanisms of water at Yucca Mountain, conservatively high flux values were used in some of the analyses. Although water from the saturated zone of Yucca Mountain has been characterized, the solubilities of many waste elements in that water have not yet been experimentally determined and are therefore estimated by calculations using a computer model (Wolfsberg et al., 1982). The models used to estimate waste element dissolution rates incorporate a number of assumptions about water flow, waste element diffusivities in the water, and solid waste form characteristics (Kerrisk, 1984; Oversby and Wilson, 1985). The assumptions that were made for the analysis are considered conservative.

Another area of uncertainty involves fracture parameters. Important parameters affecting flow, such as fracture aperture, fracture spacing, and connectivity, are poorly known. Under the conditions of fracture flow, chemical retardation factors based on equilibrium conditions may not be accurate; with fracture flow, the kinetics of adsorption, absorption, and diffusion could become important. If fracture flow occurred, then radionuclide transport could be more rapid than that under matrix flow conditions. If radionuclide transport is significantly increased by the formation of colloids or complexes, then there will be uncertainty about retardation coefficients and diffusivities.

Analyses of precipitation and the formation of particulates, colloids, and inorganic or organic complexes are generally based on qualitative assessments of the general behavior of aqueous chemical systems. Estimates

of geochemical retardation are based on the retardation factor calculated from sorption measurements. Geochemical retardation, however, is defined as a combination of the processes of sorption and matrix diffusion. This produces uncertainty in interpretations based on sorption measurements and retardation factors because other processes could also affect retardation.

The dissolution rates of elements from solid waste at Yucca Mountain were estimated by using models in which dissolution rates are limited by the diffusion of elements into water flowing past the waste (Kerrisk, 1984). Waste elements are assumed to be saturated at the waste-water interface. This model has been proposed as being more realistic than leach-rate models (Chambre et al., 1982). Experimental data that validate this proposal are now becoming available (Oversby, 1983; Chick and Pederson, 1984; Grambow and Strachan, 1984). Another model is based on the assumption that all of the water flowing through the repository becomes saturated with each waste element (Kerrisk, 1984). The results from this model are conservative; they represent upper limits on the dissolution rates of waste elements, not the expected values. A third model, based on radionuclide releases from spent fuel and high-level waste in cracked waste disposal containers (Oversby and McCright, 1984), has also been used to estimate upper limits on release rates (Oversby and Wilson, 1985).

6.3.1.2.3 Favorable conditions

(1) The nature and rates of the geochemical processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years.

Evaluation

In the discussions that follow, geochemical processes have been divided into two categories: (1) the processes that could involve mineralogic reactions and changes in mineral assemblages within the geologic repository and (2) unspecified geochemical processes that could affect the stability of the ground-water chemistry. The approach to establishing this favorable condition with regard to geochemical processes of the first category has been to identify geochemical processes resulting in mineralogic changes and to determine the nature and rate of such changes.

The dominant pre-Quaternary geochemical processes resulting in mineralogic changes at Yucca Mountain are the alteration of volcanic glass to the zeolites clinoptilolite and mordenite and to minor clay minerals and the recrystallization of this mineral assemblage to analcime, feldspar, and quartz. Although the process of zeolitization is interpreted as a diagenetic alteration of glassy tuffs below the water table, there is evidence (Hoover, 1968; Bryant and Vaniman, 1984) of possible zeolitization near or above the water table. The alteration of glass to zeolites and clay is a favorable geochemical process because it increases the radionuclide sorptive capacity of the affected rock. Although this increased sorptive capacity is a favorable condition, the increased water content may produce other unknown

effects that are not necessarily favorable. Therefore, a zeolitization rate close to zero may be the most favorable condition.

Petrofabric studies of the altered rocks, combined with information about the tectonic history of the area, indicate that the zeolitic alteration of glasses at Yucca Mountain predated the Quaternary Period (Bryant and Vaniman, 1984). A separate episode of zeolitization, localized in the lower Topopah Spring Member of the Paintbrush Tuff was probably related to the original cooling of the unit and therefore also predated the Quaternary Period (Levy, 1984b). Because this geochemical process was probably not operating during the Quaternary Period (Bryant and Vaniman, 1984), its Quaternary rate is inferred to be close to zero. Barring climatic changes that would significantly increase ground-water recharge or raise the static water level at Yucca Mountain, zeolitization should be inoperative or minor during the next 100,000 years. However, zeolitization could occur either in the upper tuffaceous beds of Calico Hills or in stratigraphically higher rock units if the environment becomes wet enough for these rocks to become saturated.

Studies of mineral-assemblage transitions associated with increasing depth and elevated subsurface temperatures suggest that the recrystallization of clinoptilolite-mordenite assemblages to analcime assemblages may have occurred during the Quaternary Period and may continue during the next 100,000 years. This recrystallization is of interest because it could reduce the amount of sorptive zeolites present along potential flow paths and thus reduce the radionuclide sorptive capacity at Yucca Mountain (Daniels et al., 1982). This type of recrystallization has taken place at Yucca Mountain at depths greater than about 945 meters (3,100 feet); factors affecting the recrystallization include time, temperature, and pore fluid chemistry (Dibble and Tiller, 1981). The time required to reach equilibrium when an intermediate metastable zeolite mineral assemblage must recrystallize to a stable analcime assemblage was estimated at tens of millions of years by Dibble and Tiller (1981) from examinations of numerous natural zeolite occurrences. The rate and extent of present and future recrystallization at Yucca Mountain can be estimated by examining the clinoptilolite-analcime boundary. The interval within which clinoptilolite disappears and analcime becomes the dominant zeolite is about 15 to 30 meters (50 to 100 feet) thick, in which clinoptilolite (with or without mordenite) coexists with small amounts of analcime (Waters and Carroll, 1981; Caporuscio et al., 1982). This transition zone occurs at depths of 450 to 750 meters (1,475 to 2,460 feet) below the repository level. If recrystallization is occurring within this interval and proceeds to completion within 100,000 years, then the amount of sorptive zeolites lost would be an insignificant portion of the sorptive zeolites remaining in the overlying rocks. Furthermore, the current understanding of the flow processes at Yucca Mountain (see Section 6.3.1.1.5) would not suggest radionuclide movement at this depth because the recrystallization occurs at least 200 meters (656 feet) below the water table.

The second category, unspecified geochemical processes, can be evaluated in terms of the predictability of the host-rock performance in isolating waste for 100,000 years into the future. In order not to affect the isolation capability, the composition of the ground water must remain unchanged or must exhibit only minor changes in the concentration of oxygen, the bicarbonate ion, and dissolved organic carbon because these are the main

constituents that affect speciation, sorption, and the solubility of waste elements in Yucca Mountain ground water (Daniels et al., 1983). To favorably affect the ability of the host rock to isolate waste, the amount of dissolved oxygen or the amount of the bicarbonate ion in solution would have to decrease because, under the present oxidizing conditions of the ground water (Daniels et al., 1983), the multivalent waste elements have higher solubilities than they would under reducing conditions and the bicarbonate ion is the major complexing ligand (Wolfsberg et al., 1982). In the first meter of surface material, the organic content of vegetation and microbes is a major reactant with the oxygen from the atmosphere that is carried along with infiltrating water. Because the amount of organics is low and also not expected to increase drastically even if the arid environment becomes semiarid during future pluvials (Section 6.3.1.4), the oxygen concentration of the water is not expected to change with time. The low organic content of the ground water (Means et al., 1983) is also not expected to change drastically or contribute to waste element complexing (favorable condition 2). The bicarbonate concentration in the ground water probably depends on carbon dioxide in the air, the respiration of plants and organisms in the soil cover, infiltration rates, and the dissolution of carbonate-containing minerals along flow paths. At this time, it cannot be stated how large the change in the bicarbonate concentration could be during the next 100,000 years. Constraints will be established during site characterization through laboratory studies and analyses of rock samples along expected flow paths.

Conclusion

Site characterization must be conducted before sufficient information will be available to identify all of the geochemical processes that could affect ground-water chemistry. It is, however, possible to draw conclusions about the geochemical processes that involve mineralogic reactions and changes in mineral assemblages. At Yucca Mountain, such processes occurred before the Quaternary Period and should be absent or minor during the next 100,000 years. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(2) Geochemical conditions that promote the precipitation, diffusion into the rock matrix, or sorption of radionuclides; inhibit the formation of particulates, colloids, inorganic complexes, or organic complexes that increase the mobility of radionuclides; or inhibit the transport of radionuclides by particulates, colloids, or complexes.

Because of the complexity of this favorable condition, the evaluation for each component is presented individually in the sections that follow.

Evaluation for geochemical conditions that promote the precipitation of radionuclides

The pH of water from wells near Yucca Mountain generally ranges from 7 to 8 (Daniels et al., 1983). Oxides of many waste elements, particularly the actinides, have high solubilities at low and high pH, with a minimum solubility in the pH range of 6 to 8 (Allard, 1982; Duffy and Ogard, 1982). Thus, the nearly neutral pH of water from the Yucca Mountain area provides conditions that favor minimum solubilities for these elements. Minimum solubility is likely to promote geochemical conditions conducive to

precipitation of dissolved material. Other conditions, if any, that promote precipitation of dissolved material at and near the proposed repository have yet to be defined.

Evaluation for geochemical conditions that promote diffusion into the rock matrix

In fractured rock with a low matrix permeability, matrix diffusion is expected to slow the movement of radionuclides in comparison to the velocity of ground water. Neretnieks (1980) calculated the extent of this effect for granite, which has a porosity of 0.004 to 0.009. In studies with nonsorbing tracers, the travel time of the tracer (defined at some arbitrary concentration relative to the input concentration) relative to the travel time of the water is proportional to the square of the porosity, all else being equal (Daniels et al., 1982). The porosity of tuffs at Yucca Mountain ranges from 0.11 to 0.50 (Johnstone and Wolfsberg, 1980). In the evaluation described below, matrix porosity is assumed to be constant, and the pores are assumed to be connected so that the diffusivity is not a function of scale. The permeability of the rock matrix is assumed to be negligible in comparison with the fracture permeability.

Travis et al. (1984) have performed modeling studies based on these theories and assumptions. By further assuming steady-state flow conditions and fractures that have not become lined by precipitation of minerals so that fracture-matrix transfer cannot occur, Travis et al. (1984) suggest that diffusion may provide delay factors (referred to as retardation factors) in Yucca Mountain tuff units of as much as 400 for nonsorbing species and several thousand for sorbing species. The physical implication of these retardation factors is that ground water (with or without dissolved radionuclides) entering a fracture will be diffused into the matrix and back into the fracture, thereby leading to a circuitous ground-water travel path. The resultant effect of this is that the radionuclide transport time will be lengthened by a factor equivalent to the retardation factor. Under transient (nonsteady-state) conditions, Sinnock et al. (1984) have estimated that the retardation factor for Yucca Mountain tuff units, using the same assumptions of fracture/matrix moisture transfer, can be conservatively considered to be 100 for nonsorbing species. This value has been qualitatively used in sections 6.3.1.1.4 and 6.3.1.4.4. to evaluate the potential effect of changing climatic conditions on radionuclide transport.

Because the proposed repository at Yucca Mountain is located in the unsaturated zone, the possibility of vapor transport of waste elements exists. Two aspects of vapor transport are important. The first is that only certain waste elements can be transported in significant quantities in the gas phase under the conditions anticipated at and near the repository. In particular, noble gases such as xenon, krypton, or radon, carbon as carbon dioxide, tritium as H_2 gas or as water vapor, or iodine as I_2 vapor are possible waste elements that can be transported as gases or vapors. The second is that the aqueous phase in the unsaturated zone can retard the movement of some waste elements because they are soluble in liquid water. These waste elements will be partitioned between the gas and aqueous phases in the unsaturated zone. All of the fission-product isotopes of xenon and krypton are stable or relatively short-lived (less than 11-year half-life) except for krypton-81, which has a half-life of 200,000 years. These noble

gas radionuclides with short half-lives will decay away during the period of substantially complete containment of the waste (300 to 1,000 years). Tritium also has a short half-life (12 years) and thus should decay away during the containment period. The radionuclide krypton-81 is present in very small quantities (Croff and Alexander, 1980) and should not pose a significant problem. Isotopes of radon will not be present as fission products, but will be produced as part of actinide decay chains. No other members of actinide decay chains are gases, so gaseous transport could only start after radon production. All of the radon isotopes have short enough half-lives (less than 4 days) to preclude gaseous transport over long distances. Two radionuclides that may be transported in the gas phase and that will be present for long periods of time are carbon-14 and iodine-129. The likely gaseous forms of both these radionuclides (CO_2 and I_2) are soluble in water and thus their transport as gases may be retarded. These topics, however, will be addressed further during site characterization.

Evaluation for geochemical conditions that promote the sorption of radionuclides

The probable flow paths from a repository in the unsaturated Topopah Spring Member to the accessible environment traverse stratigraphic zones that contain an abundance of highly sorptive minerals, particularly zeolites and clays. Water will flow from the repository downward to the water table and then laterally along paths defined by the hydraulic gradient and the hydraulic conductivity of the rock. These paths will be in part through the tuffaceous beds of Calico Hills, which contain significant quantities of zeolites and clays (i.e., clays greater than 5 percent, zeolites greater than 10 percent).

Other formations that might also be in the path of flow, the Prow Pass, the Bullfrog, and the Tram members of the Crater Flat Tuff, have zones containing zeolites and clays in variable abundances (smectite, heulandite, clinoptilolite, and (or) mordenite). Distributions of abundant (i.e., greater than 10 percent) sorptive zeolites in the rock matrix are summarized on the map and cross sections in figures 6-10 to 6-13. Four principal intervals of zeolitization have been identified at Yucca Mountain (Bish et al., 1984). These intervals are described on the following pages and in Table 6-22 for each of the drill holes on the cross sections.

1. Interval I: The zeolite- and clay-rich zone at the top of the lower Topopah Spring vitrophyre. Although thin (generally less than 3 meters (10 feet)), this interval is important because it is at the immediate base of the host rock and is everywhere above the static water level (SWL). This zeolitized interval is unique because it is within the densely welded region of a compound cooling unit, whereas zeolitization is generally restricted to the poorly welded or nonwelded margins of cooling units.
2. Interval II: The relatively thick zeolitized zone that occurs in places in the bedded, nonwelded, and poorly welded tuffs that form the base of the Topopah Spring Member and the underlying tuff of Calico Hills, and often extends into the top of the Prow Pass Member of the Crater Flat Tuff. The base of the Topopah Spring Member is the lower margin of a compound cooling unit, providing a predictable

Figure 6-10. Plan view of the Yucca Mountain area based on the map by Scott and Bonk (1984). Locations of drill holes are indicated along with the orientations of cross sections used in figures 6-11 through 6-13 with zeolite zonation represented on the geologic cross sections drawn from Scott and Bonk (1984). Several drill holes (USW H-6, WT-1, WT-2, and UE-25b#1) are projected onto the cross sections. Modified from Bish and Vaniman (1985).

Figure 6-11. Major intervals containing the sorptive minerals clinoptilolite or mordenite. The intervals within the lower Tptw (above the basal vitrophyre) consist mostly of heulandite (isostructural with clinoptilolite). Mordenite may be completely absent in some parts of these mapped intervals (e.g., in USW G-3 and GU-3). Modified from Bish and Vaniman (1985).

Figure 6-12. Major zeolite distributions, north-south cross section. Modified from Bish and Vaniman (1985).

Figure 6-13. Major zeolite distributions, from center of Figure 6-10 to the southeast. Modified from Bish and Vaniman (1985).

Table 6-22. Commonly zeolitized intervals at Yucca Mountain^{a,b}

Zeolitized intervals	USW G-1 SWL=577 m deep	UE-25a#1 UE-25b#1 SWL=471 m deep	USW G-4 SWL=541 m deep	USW H-4 SWL=519 m deep	USW H-5 SWL=704 m deep	USW H-3 SWL=754 m deep	USW GU-3 USW G-3 SWL=754 m deep
Interval I: above the lower Topopah Spring vitrophyre	Depth: 392-393 m (1 m thick) 15% cpt	Depth: 385-398 m (3 m thick) 7% cpt	Depth: 396-401 m (5 m thick) 10% (+12) cpt	Depth: 357-361 m (4 m thick) No samples	Depth: 485 m 10% cpt	Depth: 367-371 m (4 m thick) No samples	Depth: 360-364 m (4 m thick) Trace cpt
Interval II: base of the Topopah Spring unit, tuff of Calico Hills	Depth: 425-565 m (140 m thick) 52% (+17) cpt	Depth: 404-556 m (152 m thick) 67% (+6) cpt 17% (+20) mord	Depth: 420-545 m (125 m thick) 50% (+19) cpt 5% (+7) mord	Depth: 400-504 m (104 m thick) 63% (+13) cpt 8% (+12) mord	Depth: 584-594 m (10 m thick) 37% cpt	Vitric (nonzeolitized)	Vitric (nonzeolitized)
Interval III: between the Prow Pass and Bullfrog units	Depth: 622-706 m (84 m thick) 45% (+12) cpt 18% (+18) mord	Depth: 636-710 m (74 m thick) 60% cpt & mord	Depth: 600-682 m (82 m thick) 32% (+12) cpt 19% (+10) mord	Depth: 596-698 m (102 m thick) No samples	Depth: 665-689 m (34 m thick) 60% cpt	Depth: 549-610 m (61 m thick) 68% cpt	Depth: 557-613 m (56 m thick) 58% (+18) cpt
Interval IV: between the Bullfrog and Tram units	Depth: 779-823 m (44 m thick) 37% (+6) cpt 15% (+11) mord	Depth: 863-890 m (27 m thick) 4% (+4) cpt 16% (+10) mord	Depth: 828-860 m (32 m thick) 9% (+9) cpt 35% (+33) mord	Depth: 765-774 m (9 m thick) No samples	No samples	Depth: 732-760 m (28 m thick) 52% (+17) cpt 18% (+13) mord	Depth: 776-822 m (46 m thick) 36% (+8) cpt

^aData from Vaniman et al. (1984).^b1 meter (m) = 3.281 feet;

cpt = clinoptilolite and heulandite;

mord = mordenite;

SWL = static water level.

locale for zeolitization. The tuff of Calico Hills is only partly welded to nonwelded throughout and is thoroughly zeolitized across the northern and eastern part of the primary repository area. However, along the rest of Yucca Mountain this interval may be incompletely zeolitized (USW H-5) or nonzeolitized and vitric (USW GU-3) (Vaniman et al., 1984).

3. Interval III: The partly welded and bedded tuffs at the base of the Prow Pass Member and at the top of the underlying Bullfrog Member compound cooling unit. This interval is consistently zeolitized throughout Yucca Mountain in the vicinity of the primary repository area (Vaniman et al., 1984), although it merges with Interval II in Jackass Flats (data from Well J-13, to the east of the cross sections shown).
4. Interval IV: The poorly welded and bedded tuffs at the base of the Bullfrog Member compound cooling unit and at the top of an underlying cooling unit within the uppermost Tram Member. This interval persists throughout the primary repository area (Vaniman et al., 1984).

Batch sorption techniques have been used to estimate sorption ratios for many radioactive elements, including cesium, strontium, barium, radium, uranium, neptunium, plutonium, americium, technetium, europium, cerium, and, to a limited degree, selenium and tin. The sorption ratio (also known as the distribution coefficient), R_d , is defined as

$$R_d = \frac{\text{activity of radionuclide on solid phase per unit mass of solid}}{\text{activity of radionuclide in solution per unit volume of solution}} \quad (6-1)$$

Rundberg (1985) indicates that sorption ratios obtained in crushed tuff experiments, such as batch sorption techniques, are in good agreement with sorption ratios obtained on intact tuff for simple cations. More than 40 tuff samples from 9 different tuff units were obtained from cores taken at varying depths from a number of drill holes at Yucca Mountain. Tables 6-23a, 6-23b, 6-24a, and 6-24b give average sorption and desorption results for these tuff samples using ground water obtained from Well J-13. Details can be found in Daniels et al. (1982), Ogard et al. (1983a,b), Wolfsberg et al. (1983), and Bryant and Vaniman (1984).

The sorption data for many of the elements studied can be correlated with mineral composition (Daniels et al., 1982). For the alkali metals (e.g., cesium) and alkaline earths (e.g., strontium, barium, and radium), which probably exist in ground water as uncomplexed ions and sorb by ion exchange, sorption is correlated with the presence of clinoptilolite and the smectite clays, which contain exchangeable cations. Since there are large quantities of clinoptilolite directly below the proposed repository horizon, cesium, strontium, and radium should be strongly sorbed, and their movement along the flow path should be retarded.

A correlation with mineral composition is also found for the sorption of cerium, europium, plutonium, and americium, but the relation is not as clear as that for the alkali metals. However, the sorption ratios are high (100 to more than 1,000 milliliters per gram). The sorption ratios of these elements

Table 6-23a. Average sorption ratios (distribution coefficients) from batch sorption experiments on crushed tuff for Sr, Cs, Ba, Ra, Ce, Eu^{a,b} (see footnotes at end of Table 6-23b)

Strat. ^c unit	Sample	depth (feet)	Sorption ratios (milliliters per gram)					
			Sr	Cs	Ba	Ra	Ce	Eu
Tpc	JA-8	606	270(5) ^d	2,700(400) ^d	435(15) ^d			2,100(300) ^d
	YM-5	251	280(80)	5,800(800)	1,100(200)		450,000 ^d (240,000)	2,300,00 (40,000)
Tpp	G2-547	547	265(10) ^f	13,300 (1,500)	3,490(30) ^f			340(30) ^f
	G2-723	723	290(40) ^f	4,100 (600) ^f	3,500 (400) ^f			>10,000 ^f
	GU3-433	433	45(9) ^g	630(20) ^g	810(100) ^g			100(14) ^g
	GU3-855	855						
Tpt	YM-22	848	53(4)	290(30)	900(30)		1,270(40)	1,390(110)
	GU3-1203	1,203	42(1) ^f	350(30) ^f	640(40)			190(2)
	G1-1292	1,292	200(6) ^f	430(28) ^f	2,100(300) ^f	1,500(100)	66(8) ^d	140(14) ^d
	GU3-1301	1,301	28(4) ^g	160(40) ^g	570(60) ^g			45(12) ^g
	YM-30	1,264	260(80)	855(5)	3,400(1,500)		230,000 (100,000)	160,000 (50,000)
	JA-18	1,420	17,000 (3,000)	16,000 (1,000)	38,000 (18,000)		2,800 (1,400) ^e	1,400(200) ^e
Th	G1-1436	1,436	36,000 (3,000)	7,800 (500)	150,000 (24,000)		59,000 (7,000)	30,000 (2,000) ^f
	G2-1952	1,952	2,200(400) ^f	63,300 (1,100) ^f	25,000 (4,000) ^f			89(14) ^f
	GU3-1436	1,436						
bt	GU3-1531	1,531						
	YM-38	1,504	17,000 (2,000)	13,000 (2,000)	100,000 (10,000)		760(140)	1,600(200)
	YM-42	1,824	3,900(600)	17,000 (1,000)	94,000 (14,000)		49,000 (7,000)	52,000 (4,000)
Tep	G1-1854	1,854	60,000 (14,000)	13,000 (2,000)	45,000 (7,000)			15,000
	YM-45	1,930	195(14)	520(90)	1,200(100)		730(100)	1,600(200)
	G1-1883	1,883	22(0.2)	187(3)	183(12)		1,420(20)	
	YM-46	2,002	190(60)	840(6)	14,000 (6,000)		310,000 (110,000) ^f	307,000 (110,000)
	G1-1982	1,982	55(4)	1,120(110)	700(50)		560(40) ^f	970(150)
	YM-48	2,114	2,100(400)	9,000(4,000)	18,000 (6,000)		1,400(500)	2,200(500)
	YM-49	2,221	3,200(300)	36,000 (3,000)	42,000 (8,000)		550(100)	1,200(100)
	JA-26	1,995	95(35)	1,500(600)	800(300)			
Tcb	JA-28	2,001	94(20)	1,640(210)	820(50)			2,100(1,000)
	G1-2233	2,233	48,000 (3,000) ^f	13,500 (800)	250,000 (30,000)		1,400(300)	900(200)
	G1-2289	2,289	7,300(500)	37,000 (13,000)	66,000 (9,000)	46,000 (20,000)		797(10)
	YM-54	2,491	62(12)	180(40)	400(150)		150(40)	470(40)
	G1-2333	2,333	180(20)	1,400(130)	1,500(200)			2,300(400)
	G1-2363	2,363	64(3)	470(40)	235(9)	540(60)		730(50)
	G1-2410	2,410	169(1)	1,250(50)	1,780			440(80)
	JA-32	2,533	57(3)	123(4)	380(30)		82(14)	90(20)
	G1-2476	2,476	41(1)	700(40)	385(11)			3,200(100)
Tct	G1-2698	2,698	42,000 (3,000) ^f	7,700(400) ^f	63,000 (5,000) ^f		240(30) ^f	200(30) ^f
	G1-2840	2,840	860(1)	2,200(200)	2,070(70)			4,900(400)
	G1-2854	2,854	94(1) ^f	1,080(120) ^f	1,000(50)			1,300(200)
	G1-2901	2,901	68(1) ^f	1,290(110) ^f	1,600(200) ^f		42,000 (3,000) ^f	160,000 ^f (50,000) ^f
	G1-3116	3,116	2,400(17) ^f	6,600(500) ^f	12,000 (4,000) ^f		100(10) ^f	760(60) ^f
	JA-37	3,497	287(14)	610(40)	760(150)			6,000(800)
Tl	G1-3658	3,658	13,000(0)	4,950(50)	13,500 (500)		1,000(200) ^f	530(40)
Tba	G2-3933	3,933	240(60) ^f	2,500(1000) ^f	1,700(500) ^f			1,500(700) ^f

Table 6-23b. Average sorption ratios (distribution coefficients) from batch sorption experiments on crushed tuff for Am, Pu, U, Se, Tc, Np^{a,b}

Strat. ^c unit	Sample	depth (feet)	Sorption ratios (milliliters per gram)					
			Am	Pu	U	Se	Tc	Np
Tpc	JA-8	606						
	YM-5	251						
Tpp	G2-547	547	13,000(110) ^f	1,200(120)	9.4(0.1)	2(2)	0 ^f	
	G2-723	723	890,000 (49,000) ^d	>4,500	2.4(0.6)	19(2)	0 ^f	
	GU3-433	433	3,400(200) ^d	330(60) ^g	0	15(3)	0	7.9(0.1)
	GU3-855	855			10(0.7)	10(0.4)		
	GU3-916	916		250(25)			0.72(0.2)	4.9(1)
Tpt	YM-22	848	1,200(130) ^{d,e}	64(20) ^d	1.8(0.2) ^d		0.3(0.14) ^d	7.0(1.0)
	GU3-1203	1,203	1,100(120) ^g	360(40) ^g	0	(1)	0	2.7(0.1)
	G1-1292	1,292						
	GU3-1301	1,301	1,800(160) ^g	290(40) ^g	0	7(2)	0.03(0.001)	5.0(0.1)
	YM-30	1,264						
	JA-18	1,420	180(30)	120(20)	2.5(0.4)			
Th	G1-1436	1,436						
	G2-1952	1,952	1,700(70) ^f	66(6) ^f	0	2(1)		2.7(0.1)
	GU3-1436	1,436			20(2)	3(10)		
bt	GU3-1531	1,531			54(9)	5(1)		
	YM-38	1,504	14,600(1,000)	140(30)	5.3(0.2)			11.0
	YM-42	1,824						
Tcp	G1-1854	1,854						
	YM-45	1,930						
	G1-1883	1,883	470(300)					
	YM-46	2,002		77(11)				6.4
	G1-1982	1,982						
	YM-48	2,114						
	YM-49	2,221	4,300(1,400)				0.15(0.02)	
	JA-26	1,995		230(50) ^e			0.21(0.02)	9(3)
Tcb	JA-28	2,001						
	G1-2233	2,233						
	G1-2289	2,289				9(1)		
	YM-54	2,491	153(6)	80(20)	1.3(0.3)		4.2(0.5) ^h	
	G1-2333	2,333						
	G1-2363	2,363		110		25(5)		
	G1-2410	2,410			2.2(0.9)			
	JA-32	2,533	130(30)					
	G1-2476	2,476						
Tct	G1-2698	2,698						
	G1-2840	2,840						
	G1-2854	2,854						
	G1-2901	2,901		400(70) ^e	4.6(0.3)			
	G1-3116	3,116						
	JA-37	3,497	28,000 (10,000) ^e					22
Tl	G1-3658	3,658						
Tba	G2-3933	3,923	6,600(400)		1,600(30)	0	0(1)	0.1(0.006)

^aData from Daniels et al. (1982); Ogard et al. (1983a); Wolfsberg et al. (1983). If no footnote is indicated, the sorption ratio in parentheses represents the standard deviation of the mean.

^bAmbient conditions, air, 20 ± 4°C; fractions do not contain particles smaller than 75 micrometers in diameter except in fractions designated by footnote f.

^cStratigraphic units are as follows: Tpc = Tiva Canyon Member; Tpp = Pah Canyon Member; Tpt = Topopah Spring Member; Th = tuffaceous beds of Calico Hills; bt = Bedded tuff; Tcp = Prow Pass Member; Tcb = Bullfrog Member; Tct = Tram Member; Tl = older tuffs; Tba = bedded tuff.

^dNonweighted average; value in parentheses is the standard deviation of the mean.

^eSome data were rejected in averaging.

^fAverage of data for the fraction with particles smaller than 500 micrometers in diameter (contains some particles smaller than 75 micrometers).

^gNonweighted average of samples taken in two different positions.

^hPerformed under controlled atmospheric conditions of nitrogen with less than or equal to 0.2 ppm O₂ and less than or equal to 20 ppm CO₂.

Table 6-24a. Average sorption ratios (distribution coefficients) from batch desorption experiments on crushed tuff for Sr, Cs, Ba, Ce, Eu^{a,b} (See footnotes at end of Table 6-24b)

Strat. ^c unit	Sample	depth (feet)	Sorption ratios (milliliters per gram)				
			Sr	Cs	Ba	Ce	Eu
Tpc	JA-8	606	311(3)	4,600(400)	480(50)		10,000(3,000)
	YM-5	251	320(30) ^d	8,900(600) ^d	1,200(120) ^d	31,000(30,000) ^d	36,000(14,000) ^d
Tpp	G2-547	547	210(10) ^f	8,700(550) ^f	2,900(200) ^f		1,700(600) ^f
	GS-723	723	330(4) ^f	4,300(4) ^f	4,200(10) ^f		>10,000
	GU3-433	433	40(10) ^g	520(20) ^g	460(20) ^g		140(10) ^g
Tpt	YM-22	848	59(2)	365(7)	830(100)	6,500(800)	3,500(200)
	GU3-1203	1,203	47(1) ^f	340(10) ^f	720(30)		650(50) ^f
	G1-1292	1,292	120(5) ^f	510(20) ^f	1,500(100) ^{e,f}	600(200) ^f	600(70) ^f
	GU3-1301	1,301	80(20) ^g	185(20) ^g	675(60) ^g		100(20) ^g
	YM-30	1,264	210(30)	1,500(100)	3,100(600)	170,000(15,000)	11,000(700)
	JA-18	1,420	15,000(2,000)	17,500(700)	280,000 (50,000)	1,600(500) ^e	2,400(300) ^e
Th	G1-1436	1,436	87,000 (12,000)	24,000(2,000)	340,000 (90,000)	6,700(600)	5,300(600)
	G2-1952	1,952	4,200(200) ^f	46,000(1,400) ^f	40,000 (1,000) ^f		1,600(200) ^f
	YM-38	1,540	22,000	13,000	260,000	2,600	7,300
	YM-42	1,842	4,100(1,000)	21,000(2,000)	90,000	44,000(5,000)	64,000(3,000)
Tep	G1-1854	1,854	72,000 (13,000) ^e	14,000(2,000)	150,000 (40,000)		4,800(700)
	YM-45	1,930	210(20)	620(110)	1,310(60) ^f	5,800(600)	7,300(900)
	G1-1883	1,883	59(1) ^f	430(4)	440(10) ^f	2,200(100) ^f	1,350(50) ^f
	YM-46	2,002	260(20)	1,800(300)	210,000 (3,000) ^f	300,000 (50,000) ^f	31,000(2,000)
	G1-1982	1,982	322(8) ^f	2,300(200) ^f	2,780(120) ^f	7,000(800) ^f	6,370(130) ^f
	YM-48	2,114	2,700(200)	27,000(4,000)	34,000(7,000)	128,000 (300)	8,100(1,200)
	YM-49	2,221	4,400(100)	39,000(1,000)	65,000(7,000)	1,040(40)	2,100(500)
	JA-26	1,995	39(3)	1,580(90)	450(13)		2,900(200)
Teb	JA-28	2,001	114(3)	2,400(100)	1,160(20)		12,300(500)
	G1-2233	2,233	90,000 (40,000) ^f	23,000(6,000) ^f	240,000 (80,000) ^f	20,000 (13,000) ^e	5,000(2,000) ^f
	G1-2289	2,289					
	YM-54	2,491	97(9)	310(20)	660(20)	1,000(200)	1,840(110)
	G1-2333	2,333	140(13) ^f	1,230(100) ^f	1,460(130) ^f		9,900(1,200) ^f
	G1-2363	2,363	150(6) ^f	1,200(30) ^f	820(20) ^f	130,000 (6,000) ^f	6,100(300) ^f
	G1-2410	2,410	140(14)	1,120(100)	1,760(150)		6,000(3,000)
	JA-32	2,533	53(3)	175(11)	490(40)	530(120)	850(130)
Tet	G1-2476	2,476	200(4)	1,520(0)			
	G1-2698	2,698	210,000 (50,000) ^f	17,000(1,100) ^f	190,000 (80,000) ^f	2,000(400) ^f	
	G1-2840	2,840	1,540(4)	2,300(130)	2,500(200)		9,000(1,100)
	G1-2854	2,854	96(1) ^f	1,160(20) ^f	1,330(0)		5,000(200)
	G1-2901	2,901	67(1) ^{e,f}	1,380(30) ^f	1,980(30) ^f	39,000(1,000) ^f	210,000 (50,000) ^f
	G1-3116	3,116	24,000(13,000) ^f	11,000 (3,000) ^f	160,000 (80,000) ^f	3,000(1,000) ^f	8,000(3,000) ^f
Tl	JA-37	3,497	312(9)	850(50)	920(40)		11,000(2,000)
Tl	G1-3658	3,658	12,000(3,000) ^f	12,000(2,000) ^f	10,000(4,000) ^f	9,000(4,000) ^f	9,000(3,000) ^f
Tbs	G2-3933	3,933	140(20) ^f	1,400(350) ^f	1,100(200) ^f		3,000(1,100) ^f

Table 6-24b. Average sorption ratios (distribution coefficients) from batch desorption experiments on crushed tuff for Am, Pu, U, Tc, Np^{a,b}

Strat. ^c unit	Sample	depth (feet)	Sorption ratios (milliliters per gram)				
			Am	Pu	U	Tc	Np
Tpc	JA-8	606					
	YM-5	521					
Tpp	G2-547	547	17,000(1,400)	1,200(170) ^f			
	G2-723	723	2.8×10^6 (2.6×10^4)	>47,000			
	GU3-433	433	9,300(1,780) ^g	920(40) ^g			
Tpt	YM-22	848	2,500(400) ^d	1,330(140) ^d	5(2) ^d	1.2(0.3) ^d	33(5) ^d
	GU3-1203	1,203	1,300(200) ^g	920(15) ^g			
	G1-1292	1,292				0	
	GU3-1301	1,301	2,500(600) ^g	1,300(460) ^g			
	YM-30	1,264					
	JA-18	1,420	1,100(300)	350(140)	9.4(1.4)		
Th	G1-1436	1,436					
	G2-1952	1,952	5,800(1,100) ^g	350(45) ^g			
	YM-38	1,540	7,100(1,200)	1,600(300)	14,8(1.0)		24(2)
	YM-42	1,824					
Tcp	G1-1854	1,854					
	YM-45	1,930					
	G1-1883	1,883	7,200(900)	890(60)			36(10)
	YM-46	2,002					
	G1-1982	1,982					
	YM-48	2,114				1.6(0.2)	
	YM-49	2,221	3,400(400) ^e	720(90)		2.0(0.3)	12(4)
	JA-26	1,995					
Tcb	JA-28	2,001					
	G1-2233	2,233					
	G1-2289	2,289					
	YM-54	2,491	550(80)	720(40)	12(8)	38(-) ^h	
	G1-2333	2,333					
	G1-2363	2,363					
	G1-2410	2,410			8(2)		
	JA-32	2,533	2,200(600)				
	G1-2476	2,476					
Tct	G1-2698	2,698					
	G1-2840	2,840					
	G1-2854	2,854					
	G1-2901	2,901					
	G1-3116	3,116					
	JA-37	3,497	32,000(10,000)	1,400(390)	9.9(0.4)		170(50)
Tl	G1-3658	3,658					
Tba	G2-3933	3,933	1,200(410)	530(130)			

^aData from Daniels et al. (1982); Ogard et al. (1983a); Wolfsberg et al. (1983). If no footnote is indicated, the sorption ratio in parentheses represents the standard deviation of the mean.

^bAmbient conditions, air, 20 ± 4°C; fractions do not contain particles smaller than 75 micrometers in diameter except in fractions designated by footnote ^f.

^cStratigraphic units are as follows: Tpc = Tiva Canyon Member; Tpp = Pah Canyon Member; Tpt = Topopah Spring Member; Th = tuffaceous beds of Calico-Hills; Tcp = Prow Pass Member; Tcb = Bullfrog Member; Tct = Tram Member; Tl = older tuffs; Tba = bedded tuff.

^dNonweighted average; value in parentheses is the standard deviation of the mean.

^eSome data were rejected in averaging.

^fAverage of data for the fraction with particles smaller than 500 micrometers in diameter (contains some particles smaller than 75 micrometers).

^gNonweighted average of samples taken in two different positions.

^hPerformed under controlled atmospheric conditions of nitrogen with less than or equal to 0.2 ppm O₂ and less than or equal to 20 ppm CO₂.

are undoubtedly influenced by the formation of hydroxyl and carbonate complexes. Geochemical sorption will not offer much retardation for anionic species like pertechnetate.

Estimates can be made for the geochemical retardation by sorption (Sherwood et al., 1975). The retardation factor, R_f , is related to the sorption ratio, R_d , by the expression:

$$R_f = 1 + R_d (\text{density}) \frac{(1 - \text{porosity})}{\text{porosity}} \quad (6-2)$$

where the density equals the rock column density, 2.5 grams per cubic centimeter. Table 6-25 lists representative values of measured sorption data for eight radionuclide elements on samples of tuff from units most likely to be in the ground-water flow path to the accessible environment. The retardation factors, which represent the ratio of the velocity of the water to the velocity of the radionuclide under equilibrium conditions, are calculated by using Equation 6-2 and assuming porous flow, which is reasonable for the nonwelded tuff units. Except for technetium, the retardation factors significantly exceed a value of 10, indicating that the average effective radionuclide travel time to the accessible environment will be much more than a factor of 10 times longer than the average ground-water flow time to the accessible environment.

Evaluation for geochemical conditions that inhibit the formation of particulates, colloids, inorganic complexes, or organic complexes that increase the mobility of radionuclides

Species naturally present in the water at Yucca Mountain can form both solid and aqueous complexes with waste elements and thus have both favorable and unfavorable aspects (Apps et al., 1983; Daniels et al., 1983). The total organic content of water from wells near Yucca Mountain is less than 0.6 milligram per liter, and the organic species tend to have high molecular weights (higher than 300) (Means et al., 1983). This leads to organic concentrations of 1×10^{-6} moles per liter or less. The low organic content of water from Yucca Mountain will inhibit the formation of significant quantities of organic complexes with waste elements. The particulate content of water at Yucca Mountain has not yet been characterized; thus, it is not known whether particulates containing waste elements will form. Certain actinides (e.g., plutonium) are known to form colloidal particles in dilute, nearly neutral aqueous solutions (Rai and Swanson, 1981; Newton and Rundberg, 1984; Kim et al., 1984; Olofsson et al., 1984). There is not enough information available at this time to know whether geochemical conditions at Yucca Mountain will inhibit the formation of these colloids.

Evaluation for geochemical conditions that inhibit the transport of radionuclides by particulates, colloids, and complexes

Actinides leached from glass are expected to occur in the form of colloids, as has been shown for americium by Avogadro et al. (1982) and Avogadro and DeMarsily (1984). The size distribution of americium colloids in low ionic strength ground water was measured by ultrafiltration. The results of

Table 6-25. Representative sorption ratios (distribution coefficients) and retardation factors for eight radionuclide elements with Yucca Mountain tuff^a

Waste element	Welded tuff Topopah Spring Member porosity = 11%		Bedded tuff Topopah Spring Member porosity = 35%		Bedded tuff - tuffaceous beds of Calico Hills porosity = 35%		Partially welded tuff Prow Pass Member porosity = 29%		Welded tuff Bullfrog Member porosity = 23%		Nonwelded tuff Tram Member porosity = 32%	
	Sorption ratio, R_d (ml/g)	Retardation factor ^{b,c}	Sorption ratio, R_d (ml/g)	Retardation factor ^{b,c}	Sorption ratio, R_d (ml/g)	Retardation factor ^{b,c}	Sorption ratio, R_d (ml/g)	Retardation factor ^{b,c}	Sorption ratio, R_d (ml/g)	Retardation factor ^{b,c}	Sorption ratio, R_d (ml/g)	Retardation factor ^{b,c}
Americium (Am)	1,200	25,000	180	820	4,600	21,000	470	2,900	140	1,200	28,000	150,000
Cesium (Cs)	290	6,000	16,000	73,000	7,800	35,000	190	1,200	180	1,500	610	3,300
Neptunium (Np)	7	150	ND ^d	ND	11	50	6.4	40	ND	ND	28	150
Plutonium (Pu)	64	1,300	120	540	140	630	77	480	80	670	400	2,200
Strontium (Sr)	53	1,100	17,000	77,000	3,900	17,000	22	140	62	520	290	1,600
Technetium (Tc)	0.3	7	2.5 ^e	12	ND	ND	0.2	2	4.2 ^e	36	ND	ND
Uranium (U)	1.8	37	2.5	12	5.3	26	ND	ND	1.3	12	4.6	25
Barium (Ba)	900	18,000	38,000	180,000	94,000	440,000	182	1,100	400	3,400	760	4,000

^aData from Daniels et al. (1982).

^bRetardation factor = $1 + R_d \frac{(1 - \text{porosity})}{\text{density}^c}$

^cRock column density = 2.5 g/cm³.

^dND = no data available.

^eControlled atmosphere--nitrogen with less than or equal to 0.2 ppm oxygen and less than or equal to 20.0 ppm carbon dioxide. Under oxidizing conditions, these values are expected to be less than 1.0.

ml/g = milliliters per gram.

these experiments showed that 70 percent of the colloid particles are larger than 0.1 micrometer and 95 percent are larger than 0.015 micrometer. In the absence of more extensive size distribution data for actinide colloids from glass leached in water that has been in contact with tuff, this size distribution provides a reasonable baseline.

Although pore-size distributions for the tuffaceous beds underlying the repository horizon are not available, mercury-intrusion porosimetry measurements have been performed on tuff samples from the zeolitized Tunnel Bed Tuff on Rainier Mesa; the results show a median pore size of 0.02 to 0.1 micrometer. If a log-normal pore size distribution is assumed, as much as 30 percent of the tuff pores are smaller than 0.01 micrometer.

In the unsaturated tuffaceous beds of Calico Hills, water is expected to move primarily through the smaller pores. The saturation is about 50 percent, and therefore water will move through pores that are smaller than the median pore size of the rock. Considering only mechanical filtration, and assuming the above size distributions for colloid particles and tuff pore size distribution, the potential exists for the bedded tuff underlying the host rock at Yucca Mountain to filter out some of the colloidal americium. This analysis ignores the potential interaction of these colloids with the tuff mineral surfaces, which could further inhibit the transport of colloids. This analysis also does not allow for additional mechanical filtration due to the flow of water through a tortuous pore structure.

Very little modeling has been done on the transport of colloids, complexes, and particulates. Generally, all the remarks presented later in this section for favorable condition 5 should apply qualitatively. The retardation and diffusion parameters will probably be different, however, from those used for simple ions.

Conclusion

The Yucca Mountain site possesses most of the geochemical conditions listed in the statement of favorable condition 2. The pH of water from the vicinity of Yucca Mountain is in the range where most oxide and hydroxide precipitates (particularly actinides) show minimum solubility. The physical properties of the tuffaceous rocks at Yucca Mountain will promote the diffusion of radionuclides into the rock matrix. In addition, the movement of particulates and colloids may be inhibited by the presence of zeolitized bedded tuff beneath the repository horizon. This bedded tuff may act as an efficient filter for the colloids, particulates, and complexes produced by the dissolution of the waste.

The geochemical conditions at Yucca Mountain also promote the sorption of radionuclides. According to estimates of retardation caused only by sorption, the tuffs of Yucca Mountain in the saturated and unsaturated zones will provide significant radionuclide retardation along the expected flow paths to the accessible environment. There is not enough information, however, to determine whether the geochemical conditions at Yucca Mountain will inhibit the formation of particulates or colloids. There are no unusual conditions that would promote the precipitation of waste element solids other than oxides and hydroxides or that would inhibit the formation of aqueous inorganic complexes containing waste elements. The total organic content of

water from the vicinity of Yucca Mountain is very low; no significant quantities of organic complexes with waste elements will form. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(3) Mineral assemblages that, when subjected to expected repository conditions, would remain unaltered or would alter to mineral assemblages with equal or increased capability to retard radionuclide transport.

Evaluation

The three mineral assemblages at Yucca Mountain that are likely to be subjected to repository conditions are feldspar-silica, heulandite-smectite, and volcanic glass. Heulandite-smectite and volcanic glass are present in the host rock in quantities of less than 2 percent (Bish et al., 1982). The radionuclide sorptive capacity of the feldspar-silica mineral assemblages located immediately below the repository is low compared with other assemblages (Daniels et al., 1982) and is unlikely to decrease under repository conditions. Heulandite and smectite, concentrated in a zone up to 3 meters (10 feet) thick along the top of the basal vitrophyre of the Topopah Spring Member (Levy, 1984b), might be affected by the minor increase in temperatures. Smectite could reversibly collapse, but would probably regain its cation-exchanging ability when the temperature drops below the boiling point of water (Allen et al., 1984). Calculations of temperature changes due to emplacement of the waste (Johnstone et al., 1984; Morales, 1985) indicate that the maximum extent of the 100°C (212°F) isotherm will be less than about 23 meters (75 feet) vertically above the midplane of the repository, and less than about 28 meters (92 feet) below the repository midplane. The nature and permanence of temperature effects on the sorptive capacity of heulandite are not yet known; however, the potential loss of sorptive zeolites within about 28 meters (92 feet) of the repository midplane represents a very small proportion of total sorptive zeolites that are present in units that underlie the repository (Vaniman et al., 1984).

Studies of natural alteration in the volcanic glass assemblages in the Topopah Spring Member indicate that repository-induced thermal conditions could cause some alteration of the glassy rock to silica-feldspar-zeolite-smectite assemblages (Levy, 1984b). Although the radionuclide sorptive capacity of silica-feldspar assemblages is low, the high sorptive properties of zeolite-smectite assemblages (Daniels et al., 1982) suggest the possibility of enhanced sorptive capacity in the altered rock.

Most of the sorptive zeolites (i.e., clinoptilolite and mordenite) in Yucca Mountain are more than 300 meters (984 feet) below the repository, placing them at a total depth of 650 meters (2,100 feet) (Bish et al., 1984). At this depth, the maximum rock temperature will be about 60°C (140°F) at 10,000 years after waste emplacement (Johnstone et al., 1984). This represents an increase above ambient temperature of about 23°C (73°F). Smyth (1982) has suggested that clinoptilolite and mordenite in Yucca Mountain would be stable to about 100°C (212°F). The small temperature increase could affect the rate at which these minerals recrystallize to less sorptive assemblages including quartz, analcime, alkali feldspar, and possibly clays (favorable condition 1). The 50,000-year duration of the temperature

elevation (Johnstone et al., 1984) is very short compared with the time required for the mineral transformation, estimated as tens of millions of years by Dibble and Tiller (1981). Therefore, it is unlikely that significant zeolite decomposition will take place in 100,000 years.

Conclusion

Under expected repository conditions, the present high radionuclide-retardation capacity of the tuffs at Yucca Mountain is not expected to be significantly degraded and may in fact be increased. Therefore, evidence indicates that this favorable condition is present at Yucca Mountain.

(4) A combination of expected geochemical conditions and a volumetric flow rate of water in the host rock that would allow less than 0.001 percent per year of the total radionuclide inventory in the repository at 1,000 years to be dissolved.

Evaluation

At Yucca Mountain the water available to dissolve the waste forms will be limited by the site characteristics to very small amounts. Estimates of water flux through the unsaturated zone have been presented in Section 6.3.1.1.5, where an upper bound on flux of 0.5 millimeter (0.02 inch) per year has been established for the repository horizon. A value twice the upper bound of 0.5 millimeter (0.02 inch) of 1.0 millimeter (0.04 inch) per year was used in the first two calculations of waste element release rate below. The third calculation presents estimates of release rates for higher flux values that are even more unrealistic.

Two models based on different element-saturation assumptions have been developed that can be used to estimate the dissolution rates of waste elements from a solid waste form at the proposed Yucca Mountain repository (Kerrisk, 1984). The first of these is a saturation-limited dissolution model in which the entire volume of water flowing through the repository is assumed to become saturated with each waste element. The application of this model requires a knowledge of only the water flow rate per unit of waste and the element solubilities. The saturation-limited model is very conservative in that it represents the upper limit on waste-element dissolution rates. It is an upper limit because the physical layout of a repository with large spaces between waste packages would allow much of the water to pass through the repository without becoming saturated with radionuclides. In a realistic model of the dissolution of waste, diffusion of waste elements will limit the concentrations of these elements far from the waste.

The second model is a diffusion-limited dissolution model in which the water present at the waste-water interface is assumed to be saturated with radionuclides; dissolution is limited by diffusion into the water that is flowing past the waste. This model is a significant improvement over the saturation-limited model in that it accounts, in a physically realistic way, for a mechanism to transport waste elements from the solid into the adjacent water. However, in accounting for this process, the model requires information about the geometry of the solid waste, water flow in the surrounding medium, and element diffusivities that can only be estimated at this time.

Some waste elements have high solubilities; cesium is one example. It is unreasonable to assume that the dissolution rates of such elements will be limited by solubility. Elements with high solubilities were assumed to be limited by the dissolution of the bulk waste form (congruent dissolution). The bulk waste form was assumed to dissolve at a fractional rate of 1×10^{-4} per year. This represents a conservative estimate for spent fuel or high-level waste in borosilicate glass (Oversby, 1983; Kerrisk, 1984); this bulk dissolution rate was assumed for these calculations to maximize the effect of solubility on waste-element dissolution rates. Although bulk dissolution rates lower than 1×10^{-4} per year seem likely, their use in this analysis would mask the influence of solubility (Kerrisk, 1984).

Calculations were done for 10 waste elements that represent approximately 99 percent of the spent fuel activity 1,000 years after repository closure. Table 6-26 lists the elements and the solubilities used. Most of the remaining radioactivity not listed in the table comes from several low-solubility elements (e.g., niobium and zirconium); including these elements would not significantly affect the results.

Results from the diffusion-limited dissolution model have been reported for spent fuel and high-level waste (Kerrisk, 1984). This study was conducted for an inventory that contained a 50-50 mixture of spent fuel and high-level waste. The estimate of the repository area needed for waste equivalent to 1 metric ton of heavy metal (MTHM) was based on the decay heat of spent fuel at 10 years after discharge (1,135 watt per MTHM, Croff and Alexander, 1980) and an assumed maximum repository thermal loading of 10 watts per square meter. This gives 114 square meters (1,227 square feet) for each MTHM. With a very conservative flux estimate of 1 millimeter (0.04 inch) per year, a water flow of 114 liters (30 gallons) would pass through the area of 114 square meters (1,227 square feet) per year. This would represent the conditions for the maximum dissolution rate that would be calculated by the saturation-limited model. For the diffusion-limited model, the spent fuel disposal container was assumed to be 0.25 meter (0.82 foot) in radius and 4.5 meters (15 feet) long and to contain 3 MTHM; the high-level waste disposal container was taken to be 0.16 meters (0.5 feet) in radius and 3 meters (10 feet) long and to contain 2 MTHM. For a flux of 1 millimeter (0.04 inch) per year and a 10-percent porosity in the surrounding rock, the pore velocity of water past the waste was estimated at 1×10^{-2} meter (0.03 foot) per year. The apparent diffusivities of waste elements in the water were taken as 1×10^{-10} square meter (1×10^{-9} square foot) per second, including the effects of matrix tortuosity and connectivity. Details of how the results were obtained from the diffusion-limited dissolution model for these parameters and the solubilities listed in Table 6-26 are given by Kerrisk (1984). The ratio of release rate to inventory for a 50-50 mixture of spent fuel and high-level waste glass at 1,000 years after closure is 3×10^{-6} per year, or about three times lower than the 0.001-percent annual limit in the favorable condition. This result does not strongly depend on the water flux. If the bulk fractional dissolution rate is lower than the 1×10^{-4} per year assumed for these results, then the ratio of release rate to inventory will be lower. The results of experiments now under way indicate that the bulk fractional dissolution rate may be much lower than 1×10^{-4} per year (Oversby, 1983).

Table 6-26. Solubilities of elements that are the dominant contributors to spent fuel radioactivity 1,000 years after repository closure^{a,b}

Element	Solubility (moles/L)
Americium (Am)	1.0×10^{-8}
Plutonium (Pu)	1.8×10^{-6}
Uranium (U)	2.1×10^{-4}
Strontium (Sr)	9.4×10^{-4}
Carbon (C)	large
Cesium (Cs)	large
Technetium (Tc)	large
Neptunium (Np)	3.0×10^{-3}
Radium (Ra)	1.0×10^{-7}
Tin (Sn)	1.0×10^{-9}

^aThe 10 elements listed here contribute about 99 percent of the spent fuel radioactivity 1,000 years after repository closure.

^bSolubilities at pH 7, oxidizing conditions (Eh = 700 mV, where Eh is the oxidation-reduction potential), and 25°C (77°F) in water that is characteristic of Yucca Mountain (Kerrisk, 1984).

Some idea of the uncertainty of this result can be obtained by comparison with the similar result for the saturation-limited dissolution model. The saturation-limited model gives the ratio of release rate to inventory ratio as 7×10^{-6} per year for a 50-50 waste mixture at 1,000 years after closure. This upper limit for the release rate is about two times higher than the diffusion-limited result, but it is still below the 0.001 percent limit in favorable condition 4.

Oversby and McCright (1984) developed a third model for the release of radionuclides from a spent fuel waste package. Containment barrier corrosion rates are predicted to be very low under the conditions at Yucca Mountain. Data for general corrosion indicate that it will take 67,000 years to corrode away the 1 centimeter- (0.4 inch-) thick waste disposal container. Crevice corrosion rates may be slightly higher under some conditions, but are not expected to significantly affect the time required to degrade and remove the container wall. The expected failure mode for the container is stress corrosion cracking of the heat-affected zone associated with the final closure weld. It is, therefore, expected that for the 67,000 years required to remove the container by uniform corrosion, the waste form dissolution will take place in a perforated but largely intact container.

Oversby and Wilson (1985) have used the model discussed above, together with the data obtained on spent fuel dissolution in Well J-13 water, to obtain an upper limit to the expected release rates for spent fuel under Yucca Mountain conditions. They assumed bare spent fuel in a waste disposal container that had cracks in the closure weld that allowed water to collect in the container. Water was assumed to flow preferentially into the vertical emplacement holes and through the failed containers. Neither of these conditions is expected to occur; however, the purpose of the calculations was to obtain an upper limit to release rates, and for this purpose the assumptions are reasonable.

The upper limits to release rates calculated by Oversby and Wilson (1985) are as follows:

1. For uranium, actinides, and other elements controlled by the dissolution rate of the matrix, the release rate is 6.4×10^{-8} per year.
2. For elements contained partly in the pellet-cladding gap, such as cesium, there is a pulsed release followed by a gradual decrease in release until matrix dissolution control is achieved. The maximum release rate for the repository ensemble average was calculated to be 5.6×10^{-6} per year during the period when fuel pins were breaching and allowing pulsed release to occur.
3. For carbon-14, there is an initial pulsed release from the oxidized skin on the Zircaloy cladding. Further release should be controlled by the rates of dissolution of cladding and the fuel matrix. For a container failure rate of 0.1 percent per year, the release of carbon-14 would be 3×10^{-6} per year for 1,000 years, decreasing thereafter to very low values.

The data used in the calculations were for 25°C (77°F). The data of Ekland and Forsyth (1978) suggest that there will not be a large increase in dissolution rate of the matrix for the highest temperatures under which liquid water dissolution of spent fuel can occur in a Yucca Mountain repository. Tests of spent fuel in Well J-13 water at elevated temperatures will begin in late 1985. Results of these tests will be used, when available, to revise the estimate of release rates.

The cracked container model developed for spent fuel can also be used to assess glass waste form release rates. In this case the water may be assumed to collect in the open space between the top surface of the glass and the upper closure weld. The exposed surface area of the glass (no allowance for cracking) is 0.27 square meter (2.9 square feet), and the head space volume is 108 liters (28 gallons), giving a ratio of surface area to solution volume (SA/V) of 2.5 per meter. Assuming that enough water could flow through the waste disposal container in a year to replace the entire 108 liters (28 gallons), waste form dissolution under these conditions for 1 year would have a (SA/V)t scaling parameter value of 912.5 days per meter. If a cracking factor of 10 is assumed, the (SA/V)t parameter becomes 9,125. This parameter is obtained by multiplying SA/V by the time, t, of the test. The flux

through the repository horizon that would be needed to make these conditions possible would be 20 millimeters (0.8 inch) per year, a value that is 40 times the current upper bound on flux of 0.5 millimeter (0.02 inch) per year (Section 6.3.1.1.5).

Bazan and Rego (1984) have shown that the normalized release rate of lithium from defense waste processing facility 165-frit glass is less than 0.02 gram per square meter-day in J-13 water at 90°C (190°F). They used an SA/V of 50 per meter and test times up to 56 days, giving an (SA/V)t value of 2,800. The release rates measured by Bazan and Rego (1984) were close to constant over the range of 600 to 2,800 in (SA/V)t. Lithium is a very soluble element and should give an upper limit to the degradation rate of the glass matrix and to the release of radionuclides. This assumption is supported by the results of Bibler et al. (1984) on 165-frit glass in Well J-13 water.

The scaling-parameter value of 9,125 obtained under the assumptions listed above is outside the range of the present data of Bazan and Rego (1984), but within reach in future experiments. Assuming that the previously established trend continues to be valid up to 9,125 days per meter, a release rate of less than 0.02 gram per square meter per day, or 20 grams (0.7 ounce) per year, would be expected. The weight of glass in the waste disposal container is 1.7×10^6 grams (3,800 pounds), so the release rate would be slightly over 1 part in 100,000. However, the flow rate of water used in these assumptions was 40 times larger than the upper bound presented in Section 6.3.1.1.5. Under the upper bound on flux, the calculated release should be spread over 40 years and be well below the limit of 1 part in 100,000 per year.

Bates and Gerding (1985) have conducted glass release rate tests using a flow rate that is equivalent to a repository flux of 8 millimeters (0.3 inch) per year. They use a cylinder of glass capped with perforated stainless steel to simulate a degraded waste disposal container. Water is delivered by slow dripping onto the top of the specimen at the rate of one drop every 3 days. Release rates based on weight loss after 26 weeks at 90°C (190°F) were 0.5 gram per square meter. Rates based on lithium release were similar, while those for uranium were lower. Scaling this release rate to the free top surface of a glass waste disposal container (0.27 square meter (2.9 square feet) $\times 10$ for cracking) and a 1-year release time, the total release would be 2.7 grams (0.1 ounce). This corresponds to a release rate of 1.6×10^{-6} per year from the glass. If the Bates and Gerding (1985) data are adjusted to a flux of 0.5 millimeter (0.02 inch) per year, the release rate would be 1×10^{-7} per year.

Conclusion

Because of the relatively benign geochemical setting and the low flux of water in the unsaturated zone, it is expected that, for a repository at Yucca Mountain, less than 0.001 percent per year of the total radionuclide inventory 1,000 years after permanent closure would be dissolved. If the presence

of intact cladding on some of the spent fuel and intact waste disposal containers for both waste forms are considered in the calculations, the release rates are expected to be very much lower. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(5) Any combination of geochemical and physical retardation processes that would decrease the predicted peak cumulative releases of radionuclides to the accessible environment by a factor of 10 as compared to those predicted on the basis of ground-water travel time without such retardation.

Evaluation

Geochemical and physical retardation processes include (1) chemical adsorption of radionuclides onto host minerals, (2) flow governed by the matric potential, and (3) the diffusion and dispersion of radionuclides due to fractures and geometrical effects.

Most of the radionuclides listed in 40 CFR Part 191 (1985) will chemically adsorb to the tuffs of Yucca Mountain. Retardation factors for these radionuclides, as determined from equilibrium batch experiments (Daniels et al., 1982), range from a low of approximately 1 for technetium-99 to almost 1 million for radium-226. All the radionuclides studied, except for technetium-99, have retardation factors well in excess of 10, and for porous flow, the effective velocity of radionuclides is found by dividing the flow rate by the retardation factor. Except for technetium-99, geochemical adsorption will therefore greatly delay the arrival of the peak total radioactivity to the accessible environment. There is also considerable variation in the retardation factor values from one stratigraphic unit to another, and this will act to separate the various radionuclides much like a chromatographic column. This separation will result in a spreading out or stretching in time of the cumulative release, and hence, a reduced rate of release to the accessible environment (Travis et al., 1984). This effect is expected to apply along the entire path to the accessible environment, not just in the unsaturated zone.

The potential host rock at Yucca Mountain is a fractured, unsaturated tuff. The effect of fractures on flow and transport is not fully understood at this time, especially for the unsaturated zone. Preliminary analysis of water flow in fractures (Travis et al., 1984) indicates that narrow-aperture cracks will not be able to transmit water very far because of strong matric potential. Therefore, the flux of 0.5 millimeter (0.02 inch) is expected to be transported predominantly in the matrix. If flux conditions do allow fracture flow in the unsaturated region (because of the presence of wide cracks in units with high saturation), diffusion out of cracks into the rock matrix will retard the progress of radionuclides by at least a factor of 100 (Travis et al., 1984). Diffusion from fractures in the saturated zone could also retard transport compared with transport in fractures without diffusion (see favorable condition 2, part (b)).

A conservative numerical evaluation for this favorable condition was made as follows. A representative path from the disturbed zone to the water table for an estimated unsaturated zone flux of 0.5 millimeter (0.02 inch) per year was chosen. It has a travel time of 43,265 years, which is the mean

of the travel-time distributions given in Section 6.3.1.1.5. The waste disposal containers were assumed to fail at 1,000 years and the entire inventory was assumed to be instantaneously available for dissolution and transport. The peak cumulative release, neglecting retardation of any radionuclide, would then be at about 44,000 years and would be the entire inventory of 1.2×10^5 curies per 1,000 metric tons of heavy metal (MTHM) (Croff and Alexander, 1980). Alternatively, using retardation factors calculated from representative values of sorption ratios from tables 6-23a and 6-23b, the peak cumulative release would be expected at 44,000 years after closure and would consist of technetium-99, iodine-129, and carbon-14. At 44,000 years the technetium-99 inventory is 1.05×10^4 curies per 1,000 MTHM, the carbon-14 inventory is less than 10 curies per 1,000 MTHM, and iodine-129 inventory is 31 curies per 1,000 MTHM. This calculation shows that geochemical retardation alone will decrease the peak cumulative release by a factor of 11.4. Other retardation mechanisms such as matrix diffusion and dispersion have been neglected. This calculation demonstrates only that retardation processes at Yucca Mountain are capable of decreasing peak releases by at least the factor of 10 specified in the favorable condition. Because of the numerous conservative simplifying assumptions made in the calculation, it does not represent a prediction of the likely magnitude of future releases.

Conclusion

Chemical adsorption, an extremely low water flux, and radionuclide diffusion into the rock matrix all combine to decrease the predicted peak cumulative radionuclide release to the accessible environment by at least a factor of 10 as compared with predictions based on ground-water travel time without such retardation. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

6.3.1.2.4 Potentially adverse conditions

- (1) Ground-water conditions in the host rock that could affect the solubility or the chemical reactivity of the engineered-barrier system to the extent that the expected repository performance could be compromised.

Evaluation

The pre-waste-emplacement water chemistry in the host rock is not known, because water samples from the unsaturated zone of the Topopah Spring Member have not yet been obtained. However, it is assumed to be similar to the composition of samples obtained from below the water table in drill holes at Yucca Mountain (Daniels et al., 1982), because water in the saturated zone includes water that was formerly in the unsaturated zone. The ground-water samples have similar chemical compositions and, when taken as a group, are similar to water taken from Well J-13 (approximately 6.5 kilometers (4 miles) southeast of Yucca Mountain). At Well J-13, the Topopah Spring Member lies

below the water table and is the producing horizon for the well. Because of the relative uniformity of ground-water chemistry obtained from drill-hole samples, and the similarity of the ground water to that of J-13 water, the J-13 water has been used as the reference water for the repository horizon. Samples of water from the unsaturated tuffs at Yucca Mountain will be obtained when the exploratory shaft is constructed. The reference water composition will then be revised; and the potential effects of any differences between the waters drawn from the unsaturated zone and Well J-13 will be evaluated.

As shown in Table 6-27, the major components of water from Well J-13 are sodium, silicon, and bicarbonate ion, with lesser amounts of calcium, potassium, magnesium, sulfate, nitrate, chlorine, and fluorine. All other elements are present in concentrations less than 0.2 milligram per liter. The pH of the water is nearly neutral. When J-13 water was reacted with Topopah Spring tuff at 90 and 150°C (190 and 300°F), only very slight changes in anion concentrations in solution occurred (Knauss et al., 1984). The principal changes in chemistry of the water were an increase in silicon concentration to a level just below the solubility limit of cristobalite, a decrease in the concentrations of magnesium, calcium, and the bicarbonate ion due to precipitation of calcium-magnesium carbonate, at the higher temperatures, and an increase in aluminum concentration (to approximately 0.5 milligram per liter at 90°C). Results obtained using samples of the Topopah Spring Member from drill cores USW G-1, USW GU-3, USW G-4, and UE-25h#1 were consistent with those obtained from surface-outcrop material collected at Fran Ridge. This suggests that lateral variation in the chemistry of the tuff is not likely to cause major variations in the host rock water chemistry (Oversby, 1983, 1985).

Drill-core samples of Topopah Spring tuff were tested for the presence of any readily soluble material in or on the rocks. Such material is found on outcrop samples in arid climate zones and has been shown to be present at the extreme southwest spur of Yucca Mountain and Fran Ridge near Yucca Mountain (Knauss et al., 1984; Oversby and Knauss, 1983). The USW holes were drilled using drilling fluids that might have removed soluble salts; however, the materials tested from UE-25h#1 were obtained by air drilling horizontally into the side of Fran Ridge and provide a good test of whether the soluble material can be expected to occur at some distance from the surface. The sample obtained from 24 meters (78 feet) into the air-drilled hole was the closest to the original outcrop surface. None of the samples tested was found to contain any evidence for significant amounts of readily soluble material that could increase the anion content of J-13 water. This result strongly suggests that the presence of soluble salts is a surface evaporation phenomenon and that such materials are unlikely to be present at the depth of the repository. This topic will be further investigated by the examination of cuttings from the unsaturated zone characterization holes (UZ series).

To determine the effects of water chemistry on expected repository performance, one must consider the potential rates and mechanisms for the corrosion of the waste disposal containers, and the dissolution rates of the waste forms. The reference container material is austenitic stainless steel.

Table 6-27. Chemistry of J-13 well water^{a,b}

Component	Mean concentration (mg/L)	Standard deviation ^c
Cations		
Magnesium (Mg)	2.17	0.22
Manganese (Mn)	0.16	0.02
Silicon (Si)	30.7	2.3
Iron (Fe)	0.001	0.020
Strontium (Sr)	0.09	0.06
Barium (Ba)	0.021	0.014
Vanadium (V)	0.023	0.016
Titanium (Ti)	0.000	0.013
Calcium (Ca)	12.2	1.2
Lithium (Li)	0.16	0.16
Potassium (K)	6.8	2.0
Aluminum (Al)	0.003	0.011
Sodium (Na)	51.7	3.5
Anions^d		
Fluorine (F)	2.0	
Chlorine (Cl)	6.4	
Phosphate (PO ₄)	0.1	
Nitrite (NO ₂)	9.6	
Sulphate (SO ₄)	18.2	
Alkalinity as HCO ₃	135	

^aData from Daniels et al. (1982).

^bpH = 7.1.

^cStandard deviations about mean for cation data are for well water collected over six-month intervals.

^dAnion data are averages of two samples taken six months apart.

During the first 1,000 years after emplacement, uniform corrosion of this material in the repository environment is expected to cause the loss of less than 0.1 centimeter (0.04 inch) of metal from the wall of the container, which is 1 centimeter (0.4 inch) thick. The J-13 water chemistry both before and after hydrothermal reaction with Topopah Spring tuff has low concentrations of elements like fluorine and chlorine, which reduces the likelihood of pitting or crevice corrosion in the austenitic stainless steel. The relatively benign water chemistry is also unlikely to enhance any stress-assisted corrosion. Thus, there are no known ground-water conditions at Yucca Mountain that are expected to compromise the performance of the metal barrier

(McCrigh et al., 1983; Oversby and McCrigh, 1984; Oversby, 1985). The possibility exists, however, that dehydration-rehydration effects, produced as the waste disposal containers go through the elevated temperature phase, may increase the salt concentrations in the ground water near the containers, which could increase the chance for their corrosion. This scenario is discussed in more detail in Section 6.3.1.3.4.

The testing of borosilicate-glass waste forms in J-13 water, both with and without tuff present, is in progress. The results of testing with experimental samples of glass (PNL 76-68 glass) indicate that the presence of tuff diminishes the dissolution rates of the glass (Oversby, 1983). Dissolution rates of defense-high-level-waste glass in J-13 water without tuff are substantially lower than those found in deionized water (Bazan and Rego, 1984). Thus, the water conditions expected in the host rock are not expected to adversely affect the performance of borosilicate glass waste forms. On the contrary, the presence in the water of silicon leached from the host rock appears to decrease the dissolution rate of the glass matrix (Oversby, 1983).

Spent fuel has been tested in deionized water and in J-13 water at 25°C (77°F) (Wilson and Oversby, 1985). These results show that there is no increase in spent fuel dissolution and degradation in J-13 water over that in deionized water. On the contrary, there is less evidence for attack of the fuel at grain boundaries in the J-13 water, less total mobilization of fuel components (based on the inventory of elements found plated out on the reaction vessel plus those in solution), and lower solution concentrations for most actinides. Uranium is more soluble in J-13 water than in deionized water, with an apparent solubility of approximately 5 parts per million, based on the highest concentrations observed during six months of testing. The higher solubility of uranium in J-13 water is due to the bicarbonate content of the water. The results obtained are in agreement with those found by other workers using spent fuel in waters of similar compositions (Johnson et al., 1981). On the basis of these results, it is considered likely that the expected water compositions in the repository will not compromise the performance of spent fuel waste forms.

Conclusion

Ground-water conditions in the Topopah Spring Member of the Paintbrush Tuff at Yucca Mountain are expected to be such that no changes in the solubility and the chemical reactivity will degrade the engineered barrier system, and no degradation of repository performance is expected. Preliminary results for both the metal waste disposal container and for the waste forms show no detrimental effects due to host-rock water chemistry. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

- (2) Geochemical processes or conditions that could reduce the sorption of radionuclides or degrade the rock strength.

Evaluation

The zeolites clinoptilolite and mordenite are high-silica zeolites found at Yucca Mountain. They are metastable with very slow reaction rates. The

aluminum-to-silicon ratio for these zeolites is slightly variable but is generally near 3-to-15 (Caporuscio et al., 1982). For the sodium end member of such a zeolite the reaction to albite can be written:

Because clinoptilolite and mordenite contain abundant silica, when they break down, usually to feldspars or analcime, silicon dioxide is also produced. From this reaction, it can be noted that if the chemical potential of silicon dioxide is high, the reaction will tend to move toward the left, forming a zeolite mineral. If the chemical potential of silicon dioxide is low, there will be a tendency to form feldspar, or analcime if it is more stable.

Glass and cristobalite are metastable phases in tuff environments at Yucca Mountain and produce higher chemical potentials of silicon dioxide than does the stable silica mineral, quartz. Clinoptilolite and mordenite in tuffs form as alteration products of glass (Hay, 1978) and at Yucca Mountain tend to coexist with cristobalite but not with major amounts of quartz (Waters and Carroll, 1981; Caporuscio et al., 1982).

Successful laboratory syntheses of clinoptilolite have used starting materials that produce a high chemical potential for silicon dioxide (Hawkins, 1981; Chi and Sand, 1983). Fluid from 150°C (300°F) hydrothermal experiments with clinoptilolite bearing samples from the tuffaceous beds of Calico Hills at Yucca Mountain contained 470 milligrams per liter silicon dioxide, which is well above the concentration that would be in equilibrium with quartz (Wolfsberg et al., 1983). Finally, calculations using estimated thermodynamics data for Na and K-clinoptilolites and mordenites (Daniels et al., 1983) indicate that the silica concentration in solution for the zeolite transition to feldspar at temperatures between 25 and 200°C (77 and 390°F) is near that for cristobalite saturation.

These observations lead to the conclusion that clinoptilolite and mordenite are metastable minerals at Yucca Mountain. With the gradual transition of the glass and cristobalite to quartz, the clinoptilolite and mordenite become unstable and recrystallize over geologic time periods to less sorptive minerals. However, as already discussed under favorable condition 3, above, it is very unlikely that this transition will be sufficiently rapid to affect repository performance.

Conclusion

The sorptive zeolites found in Yucca Mountain (heulandite, clinoptilolite, and mordenite) are metastable, with very slow reaction rates. Through time, the zeolites might begin to recrystallize to less sorptive minerals.

However, as discussed under favorable condition 3, very little reaction is expected in the next 100,000 years. Sorptive properties and host-rock strength are not expected to be reduced by geochemical processes occurring at Yucca Mountain. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(3) Pre-waste-emplacement ground-water conditions in the host rock that are chemically oxidizing.

Evaluation

The potential host rock at Yucca Mountain lies above the water table and is in the densely welded portion of the Topopah Spring Member of the Paintbrush Formation. Pores in the rock will be partially filled with water and partially filled with air because of the unsaturated conditions. Consequently, the water can be expected to contain dissolved oxygen up to a level of 8.1 parts per million, which is the solubility of oxygen at 25°C (77 °F) and 1 atmosphere (Linke, 1965). There are no major mineral components in the potential host rock that can be expected to react with the dissolved oxygen. However, the reaction of the trace minerals in the rock (e.g., biotite, amphibole, ilmenite, and magnetite) that contain ferrous iron could consume some of the dissolved oxygen.

Although the proposed repository is in an oxidizing environment, there are some factors that could effectively reduce the amount of oxygen reaching the emplaced waste. Reductions in the oxidation state of the water could result from interaction with the austenitic stainless steel of the waste disposal containers. In addition, under mildly oxidizing conditions this steel should develop a protective oxide film that would limit further corrosion of the container (McCright et al., 1983). Thus, the pre-waste-emplacement oxidizing conditions may prolong the lifetime of the waste disposal container.

The release of radionuclides from vitrified waste in the Yucca Mountain environment is expected to be controlled by the matrix solubility of the glass, and to occur at levels less than 1 part in 100,000 per year of the inventory at 1,000 years after closure (Oversby, 1983). The pre-waste-emplacement oxidizing conditions are not expected to adversely affect the rate of release from glass waste forms. As mentioned above, the oxidation state of the water in contact with the waste forms may have been lowered by interactions with the metal container. Water contact with spent fuel may also be buffered by reaction with the Zircaloy cladding of the fuel, a reaction that could cause further lowering of the oxidation state of the water.

Oxidizing conditions in water that contacts spent fuel waste forms could produce two potentially adverse effects. First, the solubility of spent fuel in an oxidizing environment will generally be greater than that in a reducing environment (Lemire and Tremaine, 1980). This could lead to a larger release of radioactive elements from the waste disposal container under oxidizing conditions than under reducing conditions if all other factors are the same. Second, the presence of oxidizing conditions might adversely affect the lifetime of the Zircaloy cladding if the uranium dioxide were to become oxidized and cause stress rupture of the cladding.

Conclusion

The ground-water conditions at Yucca Mountain are expected to be chemically oxidizing. As discussed above, this condition could be altered after the emplacement of waste disposal containers and is not expected to cause serious problems with respect to the solubility or chemical reactivity of the engineered barrier system. Nonetheless, oxidizing conditions are expected in the pre-waste-emplacement environment. Therefore, the evidence indicates that this potentially adverse condition is present at Yucca Mountain.

6.3.1.2.5 Evaluation and conclusion for the qualifying condition on the postclosure geochemistry guideline

Evaluation

Identified geochemical processes involving mineralogic reactions have been inoperative at Yucca Mountain during the Quaternary Period or have, during this period, occurred at low enough rates and affected small enough areas that their continuation over the next 100,000 years is unlikely to affect the ability of the geologic repository to isolate waste. The pH of the water from the vicinity of Yucca Mountain is in the range where the oxide and hydroxide precipitates for most radioactive elements (particularly actinides) show minimum solubility. The matrix properties of the host rock and surrounding units favor diffusion, (favorable condition 2, part (b)), and the geochemical conditions at Yucca Mountain promote the sorption of radionuclides. The total organic content of water from the vicinity of Yucca Mountain is very low; no significant quantities of organic complexes containing waste elements are likely to form. The movement of particulates and colloids may be greatly inhibited by the presence of zeolitized tuff, which occurs beneath the repository horizon and is expected to have few fractures. Present knowledge indicates that the sorptive capacity will not significantly decrease and could even increase over the next 100,000 years. Although the sorptive zeolites (clinoptilolite and mordenite) may break down over geologic time, very little reaction is expected in the next 100,000 years. The expected geochemical conditions and water flux at Yucca Mountain will allow less than 0.001 percent per year of the total radionuclide inventory in the repository at 1,000 years after permanent closure to be dissolved. There are several retardation processes that will decrease predicted peak cumulative radionuclide release to the accessible environment by a factor of at least 100 as compared with predictions based on ground-water travel time without such retardation.

Solubility and chemical reactivity of the engineered barrier system under expected repository conditions in the Topopah Spring Member at Yucca Mountain allow satisfactory performance under expected repository conditions. Changes in the oxidation-reduction state of the water due to interaction with the austenitic stainless steel of the waste disposal container or with the Zircaloy cladding of spent fuel rods could mitigate the consequences of the chemically oxidizing pre-waste-emplacement ground-water conditions.

Conclusion

The present and expected geochemical characteristics of the Yucca Mountain site provide reasonable expectation that radionuclide releases from the engineered barrier system and to the accessible environment will meet the applicable limits and performance objectives. The engineered barrier system is expected to meet performance objectives for containment and isolation because of the benign chemistry of the unsaturated emplacement environment and the extremely low water flux. Therefore, the evidence does not support a finding that the site is not likely to meet the qualifying condition for geochemistry (level 3).

6.3.1.2.6 Plans for site characterization

A number of tests are planned to improve the understanding of geochemical conditions and processes at Yucca Mountain. Analysis of rock samples collected during construction and from lateral coring in the exploratory shaft and in drifts in the in situ test facility will provide data to better establish the vertical and lateral mineralogical and geochemical variability in the tuffaceous rocks at Yucca Mountain. Perched water, fracture-bound water, and any other mobile water in the unsaturated zone will be sampled, monitored, and analyzed to understand the types and magnitudes of chemical reactions occurring within the unsaturated zone. In addition, large blocks of rock will be obtained at various depths during construction of the exploratory shaft for chlorine-36 analyses of pore-water age. This analysis will provide supporting data for estimates of flow rates and travel times in the repository horizon.

A diffusion test is also planned during the in situ phase of testing. This test will be used to evaluate and confirm the diffusion processes and rates in the unsaturated Topopah Spring welded unit and the Calico Hills non-welded unit. Results of this test will aid in establishing confidence in the radionuclide retardation capability of the host rock.

6.3.1.3 Rock characteristics (10 CFR 960.4-2-3)

6.3.1.3.1 Introduction

The qualifying condition for this guideline is as follows:

The present and expected characteristics of the host rock and surrounding units shall be capable of accommodating the thermal, chemical, mechanical, and radiation stresses expected to be induced by repository construction, operation, and closure and by expected interactions among the waste, host rock, ground water, and engineered components. The characteristics of and the processes operating

within the geologic setting shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements set forth in 10 CFR 60.113 for radionuclide releases from the engineered barrier system using reasonably available technology.

Postclosure rock characteristics are important to the long-term isolation capability of the host rock. The mining operations during repository construction and the heat generated by the emplaced waste must not lead to conditions that would significantly diminish the ability of the site to contain and isolate the waste. If extensive changes in the host rock were induced, new pathways or barriers for radionuclide migration from the repository could result, and the isolation capabilities of the host rock could be impaired. The objective of the postclosure rock characteristics guideline is to ensure that the present and expected characteristics of the host rock and surrounding units can accommodate the thermal, chemical, mechanical, and radiation stresses expected to be induced by repository construction, operation, and closure and by expected interactions among the waste, the host rock, the ground water, and the engineered barrier system.

The postclosure rock characteristics guideline consists of two favorable conditions, three potentially adverse conditions, and one qualifying condition. The evaluations reported below are summarized in Table 6-28.

6.3.1.3.2 Data relevant to the evaluation

Summary of available data

The stratigraphic section at Yucca Mountain is composed of a sequence of welded and nonwelded tuffs; some strata are devitrified or altered, and some remain vitric (Scott and Castellanos, 1984). The strata have been subjected to varying amounts of mineral alteration, as described by Bish et al. (1984). The densely welded devitrified portion of the Topopah Spring Member of the Paintbrush Tuff at Yucca Mountain has been selected as the potential host rock (Johnstone et al., 1984) after an area-to-location screening evaluation (Sinnock and Fernandez, 1982). Studies by Mansure and Ortiz (1984) and Nimick and Williams (1984) have provided estimates of the vertical and lateral extent of the potential host rock. The relevant data for analyzing the impact of rock characteristics on waste containment and isolation include the geologic, mineralogic, physical, thermal, and mechanical attributes of the relevant rock types. The special considerations involved in disposal of waste in the unsaturated zone have been reviewed (Roseboom, 1983). The geologic attributes include the thickness and lateral extent of units (Nimick and Williams, 1984) and structural features such as fracturing and stress state. The potential host rock at Yucca Mountain is highly fractured but many of the fracture attributes, such as orientation, frequency, length, and aperture, have not yet been measured (Spengler et al., 1979, 1981; Spengler and Chornack, 1984; Maldonado and Koether, 1983). Preliminary measurements of in situ stresses have been made (Healy et al., 1982). Bish et al. (1984)

Table 6-28. Summary of analyses for Section 6.3.1.3; postclosure rock characteristics (10 CFR 960.4-2-3)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITIONS	
(1) A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the underground facility to ensure isolation.	The evidence indicates that this favorable condition is not present at Yucca Mountain: the host rock is sufficiently thick and laterally extensive to ensure isolation; however, significant lateral flexibility cannot be claimed until site-characterization data are available.
(2) A host rock with a high thermal conductivity, a low coefficient of thermal expansion, or sufficient ductility to seal fractures induced by repository construction, operation, or closure or by interactions among the waste, host rock, ground water, and engineered components.	The evidence indicates that this favorable condition is present at Yucca Mountain: the host rock possesses a low thermal expansion coefficient; calculated thermal and mechanical behavior of the host rock suggests no adverse response to be expected.
POTENTIALLY ADVERSE CONDITIONS	
(1) Rock conditions that could require engineering measures beyond reasonably available technology for the construction, operation, and closure of the repository, if such measures are necessary to ensure waste containment or isolation.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: no rock conditions identified to date are expected to require extraordinary engineering measures to ensure waste containment or isolation.
(2) Potential for such phenomena as thermally induced fractures, the hydration or dehydration of mineral components, brine migration, or other physical, chemical, or radiation-related phenomena that could be expected to affect waste containment or isolation.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: the potential host rock is expected to be physically and chemically stable; calculations indicate that thermally induced fracturing would be minor and would not be expected to affect waste containment or isolation.

Table 6-28. Summary of analyses for Section 6.3.1.3; postclosure rock characteristics (10 CFR 960.4-2-3) (continued)

Condition	Department of Energy (DOE) finding
(3) A combination of geologic structure, geochemical and thermal properties, and hydrologic conditions in the host rock and surrounding units such that the heat generated by the waste could significantly decrease the isolation provided by the host rock as compared with the pre-waste-emplacement conditions.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: no combination of host-rock properties and conditions has been identified that would be expected to cause a decrease in isolation capability because of the heat load.
QUALIFYING CONDITION	
The present and expected characteristics of the that host rock and surrounding units shall be capable of accommodating the thermal, chemical, mechanical, and radiation stresses expected to be induced by repository construction, operation, and closure and by expected interactions among the waste, host rock, ground water, and engineered components. The characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements set forth in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.	Existing information does not support the finding the site is not likely to meet the qualifying condition (level 3): the characteristics of the host rock and surrounding units are expected to permit compliance with containment or isolation requirements. Available data suggest rock characteristics are not expected to compromise performance of the waste package.

provide the bulk mineralogic data for various stratigraphic layers. A preliminary assessment of the potential for halide concentrations in the ground water of the repository environment is provided (Morales, 1985). Preliminary investigations of the corrosion of the stainless steel waste disposal containers due to the gamma radiolysis of water have been made (DOE/NVO, 1985). The effect of the heat generated by the waste container on the immediate environment around the repository horizon has been evaluated by Stein et al. (1984).

Tillerson and Nimick (1984) have described relevant physical properties including density and porosity, and heat capacity, thermal conductivity, and thermal expansion for comparison with the properties of other rock types (DOE, 1984a,b; Tuma, 1976; Clark, 1966). Mechanisms that may alter host-rock permeability have been investigated (Braithwaite and Nimick, 1984; Wollast, 1967; White et al., 1980; McVay, 1982; Moore et al., 1984). Temperature and pressure effects are yet to be investigated although limited data are available for similar rock types (Zimmerman, 1983). The temperatures expected in the repository have been calculated (Morales, 1985) and the effects have been investigated of elevated temperatures on tuff mineralogy (Bish, 1981; Bish et al., 1982; Koster van Groos, 1981; Lappin, 1980a), water movement (Stein et al., 1984; Mondy et al., 1983), and ground-water chemistry (Oversby 1983; Erdal et al., 1979; Johnstone and Wolfsberg, 1980; Daniels et al., 1982). Ground-water flux through the repository has also been estimated (Wilson, 1985). The mechanical properties needed for repository design include the elastic modulus, Poisson's ratio, cohesion, angle of internal friction, and tensile strength for intact material and such fracture properties as shear and normal stiffness, cohesion, and the coefficient of friction. The dependence of these properties on water content, confining stress, and temperature is under investigation. Preliminary designs for borehole and repository plugging and sealing have been prepared (Fernandez and Freshly, 1984; Jackson, 1984).

Assumptions and data uncertainties

Rock conditions that are influenced by geochemical and hydrologic conditions are discussed in the geochemistry guideline (Section 6.3.1.2) and the geohydrology guideline (Section 6.3.1.1). Changes in rock attributes during the operation of the repository (Section 6.3.3.2) can also be important to the postclosure behavior of the repository. This guideline addresses the rock conditions after closure and their potential effects on waste containment and isolation. In order to evaluate the effects of heating on the very near, near, and far fields for periods to 50,000 years, various waste emplacement configurations (including the preferred vertical and alternative horizontal configurations), canister loadings (1.6 and 3.3 kilowatts per canister for spent fuel and 2.16 kilowatts per canister for commercial high-level waste), and repository gross thermal loadings (50 to 100 kilowatts per acre) were assumed. Rock properties actually determined for the host rock and surrounding units were used, where available. Where specific properties for a particular unit were not available, the property was estimated by comparison with a similar rock unit. Virtually no data are available on properties of individual fractures or the effects of fractures on rock matrix properties, although experiments to measure such properties are under way in the laboratory and planned for the exploratory shaft.

Conservative assumptions were used in all of the computer analyses reported here. The characteristics of fractures are difficult to model; for these analyses the fractures were modeled as planar, ubiquitous, and non-intersecting. Models are being developed to better understand the influence of fractures. The current models also rely on sequential, rather than fully coupled, calculations. Often, averaged properties were used in the evaluations. Whenever possible, average and bounding properties were determined by statistical analysis.

Some geologic uncertainty arises because the data are derived from surface mapping and a limited number of boreholes. Nevertheless, the three-dimensional geologic model of Yucca Mountain is reasonably complete (Nimick and Williams, 1984). The material properties of the stratigraphic units are determined from cores typically 5 centimeters (2 inches) or less in diameter. Because the sample size is small, the known properties are mainly limited to those of the matrix rather than the rock mass. Also because of the small sample size, discontinuities present in the rock mass are not necessarily included in the sample. Some of the thermal and mechanical matrix properties are relatively well known because a large number of samples have been measured. In these instances, the data have been statistically analyzed to yield average values and standard deviations.

Quantitative and qualitative analyses are used in the discussion of the favorable and potentially adverse conditions. The quantitative analyses used computer models to predict the thermal and thermomechanical behavior of the rock units. Qualitative and semiquantitative analyses were used to predict mineralogical responses to the heat emitted by the waste decay, the thickness and lateral extent of the host rock, and the relation of rock characteristics to engineering requirements.

The uncertainty introduced by the computer models is poorly known at present. Evaluations are under way to investigate this uncertainty by comparing the results of different models solving the same problem. The models are also being used to predict and compare the results of specific experiments and field tests.

The preliminary assessment of possible halide concentrations in the repository environment are based on incomplete investigations that will be continued during site characterization, as will the early investigations of radiation-related phenomena.

6.3.1.3.3 Favorable conditions

- (1) A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the underground facility to ensure isolation.

Evaluation

Four potential emplacement horizons in Yucca Mountain have been evaluated (Johnstone et al., 1984), and the unsaturated densely welded devitrified portion of the Topopah Spring Member has been selected as the preferred

repository horizon. The other three units were also judged to meet performance requirements for waste isolation, but ranked below the Topopah Spring Member. These units are the tuffaceous beds of Calico Hills and the Bullfrog and Tram members of the Crater Flat Tuff. The ranking criteria included (1) ground-water travel time, (2) allowable gross thermal loading, (3) excavation stability, and (4) relative economics. For the unit evaluation, the Topopah Spring Member was limited to the zone containing less than 5 percent lithophysal cavities. At these low percentages, lithophysal cavities have little effect on the thermomechanical properties of the rock. At what percentage the lithophysal cavities become a concern will be determined during site characterization. For planning purposes, the underground facility has been placed in the relatively lithophysae-free section (less than 15 to 20 percent) that lies above the basal vitrophyre (Mansure and Ortiz, 1984). To date, however, no thermal or mechanical characteristics have been identified that would make the units below the proposed emplacement horizon (including the vitrophyre) unacceptable for the placement of waste.

Area 1 on Figure 6-14 is the primary area for locating the underground facility. It contains relatively few faults and rare fault breccias (Scott and Bonk, 1984). The surface and subsurface geologic exploration of Yucca Mountain has concentrated in this area and in the immediately surrounding area that has a relatively low fault density. Available site data indicate that rock with acceptable characteristics may be present within areas 2 through 6, and perhaps even outside these areas (Mansure and Ortiz, 1984; Sinnock and Fernandez, 1982).

Analysis of the output from a three-dimensional computer graphics model of Yucca Mountain (Nimick and Williams, 1984) indicates that area 1 contains approximately 890 hectares (2,200 acres) although minor faults and breccia and blocks rotated to steep dips may occupy some of the area; approximately 749 hectares (1,850 acres) of area 1 are potentially usable on the basis of the disqualifying condition for erosion, which requires a 200-meter (656-foot) overburden. The present estimates of waste inventories and the current repository design concepts (Mansure and Ortiz, 1984) require 616 hectares (1,520 acres) for a repository. Area 2 (Figure 6-14), a primary area for extending the underground facility from area 1, covers approximately 910 hectares (2,250 acres) and is similar to area 1 in fault density. Data for area 2 are limited to those obtained from surface mapping and extrapolation from drill-hole data obtained mainly in and around area 1. If extension of the underground facility from area 1 is required to provide lateral flexibility, additional geologic information may be obtained as part of site characterization to determine how much of this area is usable. Area 3 covers approximately 162 hectares (400 acres). Small portions of this area might not pass the disqualifying condition for erosion which requires 200 meters (656 feet) of overburden. Area 4 covers approximately 607 hectares (1,500 acres) and also may have rock characteristics similar to the other areas, but fewer data exist for this area, and it is farther from the primary repository area. As in area 3, portions of area 4 might not pass the disqualifying condition for 200 meters (656 feet) of overburden. Area 5 contains about 202 hectares (500 acres), and area 6 contains 1,072 hectares (2,650 acres). Area 6 has a very complex fault structure with steeply dipping faults, and part of it may not meet the 200-meter (656-foot) overburden requirement. Flexibility in lateral extent cannot be demonstrated at this time because the data for areas 2 through 6 are limited.

Figure 6-14. Potential repository expansion areas. Area 1 is the primary area for the underground facility. See text for detailed discussion of areas 1, 2, 3, 4, 5, and 6. Cross section A-A' is shown on Figure 6-16. Modified from Mansure and Ortiz (1984).

The basic requirements for the thickness of the geologic section are (1) the presence of sufficient overburden to ensure a low probability of uncovering the waste by erosion and (2) sufficient thickness of host rock to provide the volume envelope required for the underground facility. The thickness of the erosional barrier at Yucca Mountain is more than 300 meters (984 feet) over about 50 percent of area 1. Figure 6-15 shows the thickness of the overburden above the midplane of the repository envelope, which is conservatively assumed to be 45 meters (150 feet) thick (Mansure and Ortiz, 1984). To date, exploration in area 1 has revealed sufficient thickness of the potential host rock to isolate the waste.

Figure 6-16 is a cross section along approximately A-A' in Figure 6-14 showing the possible location of the underground facility. The potential repository host rock is the lower portion of the Topopah Spring Member, designated Tpt on this figure. A three-dimensional model of area 1 that incorporates surface and subsurface data (Nimick and Williams, 1984) was used to determine that the host rock is sufficiently thick to provide flexibility in selecting the depth of the underground facility. For most of the usable portion of area 1, the thickness of the potential host rock is over three times the thickness required to contain the repository. Mansure and Ortiz (1984) show that the approximate thickness of the preferred host rock is on the order of 100 to 175 meters (330 to 575 feet) within area 1. Also shown in Figure 6-16 are the projected underground locations of some faults identified at the surface. These faults do not restrict the location of a repository, because the simple presence of a fault is not necessarily detrimental to a repository located in the unsaturated zone; they could, in fact, be advantageous (Roseboom, 1983). There is no reason to believe that constraints on depth, configuration, and location of the underground facility will in any way compromise the potential isolation performance of the Yucca Mountain site. With the low water flux that is expected through the repository, and the more than 185 meters (610 feet) of unsaturated rock between the repository and the water table, possible constraints resulting from limited vertical or lateral extent of the host rock are unlikely to have significant effects on the isolation provided by the thick unsaturated zone.

Conclusion

The potential host rock within the primary repository area at Yucca Mountain is sufficiently thick to provide significant vertical flexibility in the placement of the repository to insure isolation. The potential host rock also provides sufficient lateral extent to insure isolation, but provides only limited lateral flexibility. However, considering only the primary area, this favorable condition cannot be claimed for lateral flexibility in repository placement. Therefore, the evidence indicates that this favorable condition is not present at Yucca Mountain.

(2) A host rock with a high thermal conductivity, a low coefficient of thermal expansion, or sufficient ductility to seal fractures induced by repository construction, operation, or closure or by interactions among the waste, host rock, ground water, and engineered components.

Figure 6-15. Approximate outline of primary repository area showing areas with greater than 200 and 300 meters (656 and 984 feet) of overburden above the midplane of the repository. Modified from Mansure and Ortiz (1984).

Figure 6-16. Approximately east-west cross section of primary repository area showing possible location of the underground repository envelope. For approximate location of cross section A-A', see map view in Figure 6-14. Modified from Mansure and Ortiz (1984).

Evaluation for thermal conductivity and thermal expansion

Two points bear on the discussion of this condition for the Yucca Mountain site. First, the site is in the unsaturated zone. Favorable condition 5(iv) in Section 6.3.1.1 notes that for an unsaturated zone repository, freely draining strata are desirable, and Yucca Mountain meets this favorable condition. Second, the Topopah Spring Member is highly fractured. It is therefore expected that significant thermally induced expansion can occur without generating sufficient stresses to cause new fracturing.

The thermal conductivity and the coefficient of thermal expansion for a variety of rock types are shown in Table 6-29. The value for the coefficient of thermal expansion of all rock types shown in the table is low when compared with values for salt. The absolute values of the thermal conductivity and coefficient of thermal expansion can be meaningfully evaluated only when combined in an analysis that includes relevant physical properties, additional thermal and mechanical properties, details of repository design, canister loading, and gross thermal loading. Such analyses (Johnstone et al., 1984) have shown (1) that the effect of the repository on the surrounding rock is small because the rock can accommodate the expected mechanical and thermal stresses; and (2) that there is considerable flexibility in repository design, canister loading, and gross thermal loading to minimize the effect of any adverse rock response that may be identified in the future. The analyses indicate that the thermal conductivity and the thermal expansion coefficient of the densely welded Topopah Spring Member at Yucca Mountain will not adversely affect the containment and isolation capabilities of the repository.

Evaluation for ductility to seal fractures

The ability to seal fractures is not a favorable condition for a repository in the unsaturated zone. The sealing of fractures could lead to repository saturation because of the formation of a barrier to water flow and the development of a perched water zone that would not exist in a freely draining system.

The current data for the Topopah Spring matrix show essentially elastic behavior up to the onset of brittle failure. Typically, the axial strain to the point of failure in compressive tests does not exceed 1 percent. Studies of the effects of water and elevated temperatures on the mechanical behavior of tuff are under way, and results will be reported in the future. But according to present data, the Topopah Spring tuff does not have sufficient ductility to seal induced or preexisting fractures. As discussed under potentially adverse condition 3, it is unlikely that sealing will occur by other processes, such as mineral precipitation from solution.

Conclusion

The potential repository host rock at Yucca Mountain will accommodate the thermal and mechanical stresses developed during the period of peak temperatures with no adverse effect on waste containment and isolation. The coefficient of thermal expansion of tuff is low when compared to salt and the thermal conductivity is intermediate when compared to other common rock types.

Table 6-29. Thermal rock properties for a variety of common rock types

Rock type	Temperature (°C)	Thermal conductivity (W/m-°C)	Thermal expansion (10 ⁻⁶ /°C)
Basalt ^a	20-200	1.5-1.8	6.0-6.5
Granite ^b	0-100	1.8	8.4
Salt ^c	50-250	2.6-3.4	36.5-46.5
Sandstone ^d	20-100	2.1	10 $\pm$ 2
Slate ^b	20-100	1.8	8.0 $\pm$ 1
Welded tuff ^e	Ambient to 200		
	Saturated	1.8 $\pm$ 0.4	10.7 $\pm$ 1.7
	Dry	1.6 $\pm$ 0.4	NA

^aData from DOE (1984a).

^bData from Tuma (1976).

^cData from DOE (1984b).

^dData from Clark (1966).

^eData from Tillerson and Nimick (1984).

The host rock is not sufficiently ductile to seal fractures; such sealing is, in fact, undesirable for a repository in the unsaturated zone. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

6.3.1.3.4 Potentially adverse conditions

(1) Rock conditions that could require engineering measures beyond reasonably available technology for the construction, operation, and closure of the repository, if such measures are necessary to ensure waste containment or isolation.

Evaluation

The evaluation of the technology required to deal with rock conditions during the preclosure phase (Section 6.3.3.2) identified no situations that would require engineering measures beyond reasonably available technology. Rock conditions that could seriously threaten waste containment by the waste package, or waste isolation after the package is breached, are considered in

this section; they include the chemical environment, mechanical behavior (including the effects of heat), hydraulic conductivity, and shaft and borehole sealing. Most of the rock-property data collected to date are from surface mapping and measurements on core samples.

The chemical environment is benign with regard to the corrosion and leaching from the waste form (Section 6.3.1.2). Stress-induced corrosion could be of concern if the mechanical behavior of the rock subjects the waste disposal containers to severe stress. This problem is currently under investigation. The rock is expected to be strong, with little likelihood that blocks would fall on the waste containers and breach containment, although mining experience will be needed to confirm this expectation. Heat is expected to cause limited fracturing around the waste emplacement hole; limited testing in similar rock supports this expectation (Zimmerman, 1983). The rock fracturing is also expected to have minimal effect on containment and isolation. If the thermally induced rock fracturing around boreholes does become a problem, it appears to be solvable with reasonably available technology. Hole liners, emplaced to ensure retrievability, could both lessen and delay potential adverse effects but would not necessarily eliminate them. Work is continuing on the effects of heat and water on the mechanical behavior of the rock.

Hydrologically, the repository horizon is freely draining. At present, no difficulties have been identified regarding shaft and borehole sealing. Analyses indicate that no backfill is necessary in access or emplacement drifts. Shafts and ramps would be backfilled at the end of the retrieval period. A plug or seal would be used to support the surface barrier system in the shafts and separate it from the shaft interior, which would be filled with a coarse, unreactive material, such as crushed tuff. This material may be graded in size to minimize settlement, and additional plugs could be emplaced to provide support for fill immediately above each plug. The current plans are to use permeable plugs and backfill so that any water can drain to the bottom of the shaft. Removal of the concrete shaft liner from the junction of the shaft and access drifts to the bottom of the shaft would enhance drainage into fractures. Ramps would be sealed in a similar fashion except that dams could be installed at intervals to divert water flow. Exploratory boreholes extending below the repository level would be filled with grout, slurry, or a tamped substance containing sorptive materials. Plugs may be needed to support this material; below the plug, standard well-plugging procedures can be followed. Above the repository level or for shallow boreholes, a granular material or grout can be used (Fernandez and Freshley, 1984; Jackson, 1984). None of these sealing concepts are expected to require engineering measures beyond reasonably available technology.

Conclusion

No rock conditions have been identified at the Yucca Mountain site that would require extraordinary engineering measures to seal shafts and boreholes and to ensure waste containment and isolation. Existing technology is adequate for constructing, operating, and closing the repository in a manner consistent with the objectives of waste containment and isolation. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(2) Potential for such phenomena as thermally induced fractures, the hydration or dehydration of mineral components, brine migration, or other physical, chemical, or radiation-related phenomena that could be expected to affect waste containment or isolation.

Evaluation for thermally induced fractures

The potential host rock at Yucca Mountain is the Topopah Spring Member, which is a highly fractured (Spengler et al., 1979, 1981; Spengler and Chornack, 1984; Maldonado and Koether, 1983; Scott and Castellanos, 1984), unsaturated, densely welded tuff. In examining the thermomechanical response of the rock in the near and the far fields for short and long time periods, Johnstone et al. (1984) made calculations with state-of-the-art, finite-element, thermomechanical computer codes that accounted for fractures by a "ubiquitous joint model" and geologic layering (i.e., stratigraphy). These calculations are considered preliminary. Evaluations are under way to reduce the uncertainties in the model; however, confidence in the validity of the model is based upon mining experience and field tests in similar devitrified, densely welded tuff (G-Tunnel at Rainier Mesa). The physical, thermal, and mechanical properties were based on laboratory or field measurements for both average and limit values when available, or they were estimated by comparison with similar units if required data were not available. In particular, thermal-expansion coefficients that accurately describe the cristobalite phase transition in the Topopah Spring Member were available (see the evaluation of potentially adverse condition 4, Section 6.3.3.2). In situ stresses were estimated because no measurements had been made at the Yucca Mountain site when the evaluation began. Subsequent measurements were in reasonable agreement with the estimates (Johnstone et al., 1984; Healy et al., 1982). For a repository in the Topopah Spring Member with a gross thermal loading of 57 kilowatts per acre (approximately 3.0 kilowatts per container), calculations predicted no thermally induced fracturing of the matrix in either the near or the far field.

For a higher waste disposal container heat load of 3.3 kilowatts per container, thermomechanical calculations predict the potential for rock fracturing in the immediate vicinity (very near field) of the waste-emplacement hole, extending less than 10 centimeters (4 inches) into the rock. Such fracturing is not expected to affect waste containment or isolation. In spite of the possible decrease in thermal conductivity, such fracturing may be desirable because of the increased surface area available for radionuclide retardation. Hole-wall degradation has not been observed in small-diameter-heater tests in tuff at G-Tunnel (Zimmerman, 1983).

For the conditions used in the calculations by Johnstone et al. (1984), the results indicate that the potential for thermally induced fracturing is very low. More important, however, the repository thermal loading can be adjusted if it is discovered that thermal effects could become potentially adverse. With the expected low flux of less than 0.5 millimeter (0.02 inch) per year (see Section 6.3.1.1.5), no mechanisms have been recognized whereby thermally induced fractures could threaten containment of isolation performance at the Yucca Mountain site.

The mineral components that have the potential for hydration or dehydration are volcanic glass, smectites, and the zeolites clinoptilolite, mordenite, and analcime. The Topopah Spring Member contains little zeolite or volcanic glass in the horizon of interest. South of Drill Hole Wash, the member generally contains less than 3 percent smectite. More than 98 percent of the host rock within the primary repository area is composed of alkali feldspar, cristobalite, quartz, and tridymite; however, tridymite is generally not present in the potential repository horizon (Bish et al., 1984). Hydrous minerals are not present in the repository horizon in large enough quantities to cause significant dehydration effects. Rock units in Yucca Mountain at depths of 300 meters (984 feet) or more below the repository horizon contain an abundance of hydrous phases, including smectite, clinoptilolite, mordenite, and analcime (Bish et al., 1984). Cross sections of the zeolite intervals below the repository horizon are shown in figures 6-10 through 6-13 in Section 6.3.1.2. The extent to which dehydration and contraction will affect waste isolation, however, will depend on the distribution of hydrous minerals in the host rock, the temperature rise imposed on the minerals, and the water vapor pressure.

The maximum temperature experienced at 50 meters (160 feet) below the repository horizon is predicted to be well below 100°C (212°F) (Johnstone et al., 1984). Under these conditions, smectites, zeolites, and glass will dehydrate only if the water-vapor pressure is low (Bish, 1981; Bish et al., 1982). Assuming a gross thermal loading of 57 kilowatts per acre, maximum temperatures have been determined as a function of distance from a spent fuel repository (Morales, 1985). The center of the repository will reach a maximum temperature of 117°C (243°F) 60 years after emplacement, while the temperature would be 71°C (160°F) at the repository edge. Fifty meters (160 feet) beyond the repository edge, the temperature will peak at 49°C (120°F) at 111 years after emplacement. The calculations can be summarized by noting stand-off distances that are required to stay below a particular temperature. To ensure that temperatures never rise above 100°C (212 °F), you must be approximately 23 meters (75 feet) vertically above the center of the repository; the temperature at the edge of the repository will never reach 100°C (212°F). This indicates that dehydration of the minor amounts of zeolites or clays within the host rock (less than 2 percent) beyond a distance of about 23 meters (75 feet) is unlikely, and as indicated earlier, all major zeolitized rock units are at least 100 meters (328 feet) below the repository midplane (see Section 6.3.1.2).

Dehydration reactions involving smectites, clinoptilolite, and mordenite are reversible when heating is below 200°C (392°F) (Bish, 1981), and the presence of water vapor significantly increases the temperature of dehydration for smectites (Koster van Groos, 1981) and probably for zeolites. Therefore, such reactions, even if they occur in the far field, will probably be reversible and will not affect waste isolation.

One additional mineralogical factor that should be considered is the abundance of cristobalite in the very near field. The transition from alpha to beta cristobalite, occurring between 235 and 260°C (455 and 500°F) in confined tests (Lappin, 1980a), gives rise to a slightly increased thermal

expansion. Because of the high transformation temperature, the potential for this transformation to occur is limited to the very near field of the waste package and is unlikely to affect waste isolation because cristobalite is not important in retardation.

Evaluation for brine migration

Although brine is not found in the tuff at Yucca Mountain, several scenarios have been identified that could possibly concentrate halide ions in the ground water in the repository environment. These scenarios include (1) salt deposition on the waste container by evaporation of water dripping on the hot waste disposal container from a seeping fracture from a transient percolation event, followed by redissolution of these salts in the ground water, and (2) precipitation of halide salts contained in the ground water in the surrounding rock matrix as the rock dries out from the heat of the waste disposal container. Subsequent dissolution may occur when the rock is resaturated after the dry-out period.

A preliminary study was performed to determine if either of the above scenarios represent viable processes for concentrating halides in the ground water at Yucca Mountain (Morales, 1985). The first scenario is not relevant because the existence of a hot waste disposal container should prevent any slow seepages in its immediate vicinity from occurring. The second scenario could possibly increase salt concentrations in the rock surrounding the waste disposal container, but probably only by a factor of 10 and only for times immediately following the dry-out period. Furthermore, a mechanism for transporting the concentrated ground water across the borehole wall (and air gap) has not been identified. However, even if this groundwater could contact the waste container, performance (corrosion and waste-form dissolution) should not be adversely affected by such salt concentration increases. This topic will be addressed in more detail during site characterization.

Radiation-related phenomena

Investigations of the effects from gamma irradiation of different candidate stainless steels submerged in water from Well J-13 have begun. Preliminary results from these studies indicate that high-intensity gamma radiation increases the corrosion potentials of the stainless steels (DOE/NVO, 1985). The corrosion mechanism is thought to be the production of hydrogen peroxide, a strong oxidant, under gamma radiolysis of the water. This effect is expected to be insignificant under actual repository conditions, however, because heat from the waste disposal containers will probably dry out the immediate environment of the containers for 500 to 1,000 years after closure (Stein et al., 1984). Gamma radiation will have decreased to insignificant amounts before liquid phase radiolysis can occur. Thus, after the thermal period, the potential will no longer exist for increased oxidizing conditions due to radiolysis.

Conclusion

The potential host rock at Yucca Mountain is a physically and chemically stable, densely welded tuff that would be little affected by expected repository conditions. More than 98 percent of the rock is composed of alkali

feldspar, cristobalite, quartz, and tridymite, all nonhydrous minerals. The potential host rock is highly fractured, and any additional thermally induced fracturing would be minor and would not adversely affect waste containment or isolation. No other physical, chemical, or radiation-related phenomena have the potential for adversely affecting waste containment or isolation. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(3) A combination of geologic structure, geochemical and thermal properties, and hydrologic conditions in the host rock and surrounding units such that the heat generated by the waste could significantly decrease the isolation provided by the host rock as compared with the pre-waste-emplacement conditions.

Evaluation

Three categories of heat-related effects have been identified as potentially applicable to this condition: (1) changes in the radionuclide retardation capability, (2) changes in host-rock permeability due to matrix dissolution, and (3) convective transport of radionuclide-contaminated ground water. The basis for evaluating each of these three concerns is discussed separately below.

Evaluation for thermal effects on radionuclide retardation

Heat-driven rock and ground-water interactions along with absolute temperature increases could affect radionuclide sorption and thus the retardation capability of the host rock. The rock and ground-water interactions could cause this by altering the mineral phases present and the ground-water solution chemistry. However, elevated-temperature experiments on the interaction of Topopah Spring tuff with water from Well J-13 indicate that an emplaced heat source should produce very little change in ground-water chemistry and primary mineralogy of the Topopah Spring Member (Oversby, 1983). This study also noted that the anionic composition (radionuclide-complexing agents) of the water remains relatively constant. Therefore, the effect of increased temperature on radionuclide solution chemistry should be minimal. The lack of significant thermally induced mineral alteration is also addressed in favorable condition 3 for geochemistry (Section 6.3.1.2).

The direct effect of higher water temperatures on the sorption process has been superficially investigated (Erdal et al., 1979; Johnstone and Wolfsberg, 1980; Daniels et al., 1982). These limited studies showed, that in general, temperature changes between 20 and 70°C (68 and 158°F) have only a minor effect on sorption. For most elements studied, sorption is slightly greater at the higher temperatures (sorption coefficients increased by up to a factor of 5). The exceptions include a few lanthanides and actinides, which showed very little or a slightly negative temperature response. As the temperature is increased, retardation because of diffusional processes will not be decreased.

Evaluation for host-rock permeability changes

The heating and subsequent cooling of ground water as it flows through the host rock could induce mineral dissolution and precipitation processes, which, in turn, would change the permeability. Currently, the magnitude of the changes in permeability that would adversely affect isolation have not been identified. However, a study has been conducted that shows that, for the expected quantities of both porous and fracture flow, the potential porosity and permeability changes are not significant (Braithwaite and Nimick, 1984). In this analysis, it was assumed that the infiltrating ground water would maintain equilibrium saturation with respect to amorphous silica. This is a reasonable bounding assumption because of the following factors:

1. Dissolved-silica concentrations constitute a major control on silicate-phase dissolution (Wollast, 1967; White et al., 1980; McVay, 1982).
2. The predicted quantity of mass transfer is greater than that measured experimentally (Braithwaite and Nimick, 1984).
3. Rates of equilibration between ground-water and rock systems are very slow at the low temperatures predicted for waste isolation in the unsaturated zone (Oversby, 1983).

A predicted time-dependent temperature gradient was coupled with the assumptions about amorphous-silica compositional control to determine the net change in porosity as a function of time and position. The results for spent fuel loadings of both 57 and 90 kilowatts per acre indicated that the maximum cumulative increase in porosity would be a volume fraction of only 0.00005 and that a decrease in porosity would occur only near the repository horizon. The net precipitation is mainly due to water vaporization and would decrease the void fraction by approximately 0.00001. This latter result probably addresses the critical issue because precipitation during downstream cooling represents a potential for plugging pores or fractures. However, these small changes, even if restricted to existing fractures, are not sufficient to significantly affect permeability.

Laboratory experiments with tuff samples from the Topopah Spring Member (Moore et al., 1984) also support the idea that changes in host-rock permeability are likely to be very small. A core sample 7.6 centimeters (3 inches) in diameter with a hole in the center was subjected to a temperature gradient of 100°C (212°F) between the inner and the outer edge. Ground water from Well J-13 was passed through the sample under confining and pore pressures corresponding to a burial depth of 1.2 kilometers (0.75 mile). The permeability of the tuff at room temperature was 3 microdarcies. After heating to 150°C (302°F), the value increased to 6 microdarcies, slowly increased for 1 week to 10 microdarcies, and then remained stable for 2 weeks. These results provide laboratory support for the claims that permeability changes that could cause significant changes in transport are unlikely in the very near field. The pH of the fluids discharged from the low-temperature outer edge of the sample was very close to that of Well J-13 water, and the concentrations of ionized species remained low, near that of Well J-13 water.

Evaluation for the convective transport of radionuclide-contaminated ground water

Thermally induced convective transport could conceivably reduce the time of ground-water travel through the host rock. If this process occurred in ground water that had been in contact with the waste, a decrease in the isolation provided by the host rock could result. Convection can occur in both vapor and liquid phases.

Free convective liquid-water transport, which is caused by density differences or buoyancy effects, can occur in porous media saturated with water. A corresponding mechanism for the free convective transport of liquid water (and therefore radionuclides) in the unsaturated zone is difficult to formulate. Nevertheless, free convection in the saturated zone would place an upper bound on the possible effect in the unsaturated zone. A preliminary study of the effects of convection on energy transfer in a saturated tuff medium (Mondy et al., 1983), showed that even with a thermal driving force well over 100°C, the maximum effect of free convection (if it occurred) would be a very small temperature increase, 2 to 3°C (4 to 5°F), occurring for less than 60 years. The highest induced water velocity would be less than 1 millimeter (0.04 inch) per year. Overall flux through the host rock would remain limited to less than 0.5 millimeter (0.02 inch) per year, which is insufficient to cause radionuclide releases to the accessible environment that would exceed the U.S. Environmental Protection Agency limits (see Section 6.4.2). According to these results, the lower temperatures and the unsaturated conditions actually expected for Yucca Mountain should preclude a decrease in host-rock isolation due to the convective transport of radionuclide-bearing ground water.

Conclusion

No combinations of geologic structure, geochemical and thermal properties, and hydrologic conditions have been identified that would cause the host rock to respond to the waste-imposed heat load in such a way that waste isolation would be compromised. Neither thermally enhanced rock-water interactions nor thermal effects on sorption are expected to reduce the isolation potential of the host rock at Yucca Mountain. Permeability changes due to host-rock dissolution and precipitation processes should not be significant, and the convective transport of radionuclide-bearing ground water is not expected in the low-temperature, unsaturated conditions at Yucca Mountain. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

6.3.1.3.5 Evaluation and conclusion for the qualifying condition on the postclosure rock characteristics guideline

Evaluation

The evaluation of the site against the preclosure rock characteristics guideline (Section 6.3.3.2) discusses worker safety and the ease and cost of repository siting, construction, operation, and closure. The results of that

evaluation show that currently available technology will be sufficient for all engineering and safety requirements. In addition, no unusual or exotic materials will be required. The geohydrologic and geochemical conditions are described in sections 6.3.1.1 and 6.3.1.2, respectively. In both sections, Yucca Mountain is considered suitable for site characterization as a potential repository site.

The preliminary thermomechanical analyses in Johnstone et al. (1984) show that the repository host rock can accommodate expected mechanical and thermal stresses after closure. They also note that the heat load can be adjusted to account for unforeseen problems. Mansure and Ortiz (1984) report that limited lateral flexibility in the placement of the repository in the primary area should be overcome by contiguous areas that are likely to be suitable for waste emplacement. The study of interactions among the waste, host rock, ground water, and engineered components is an ongoing task. To date, no difficulties have been identified. Because the repository would be in the unsaturated zone, ground-water interactions with the waste package could occur only at temperatures of less than 100°C (212°F). Above 100°C (212 °F) the water evaporates and moves to a cooler region. Such behavior tends to increase the effective thermal conductivity and to decrease the temperature in the rock mass near the heat source. As noted in potentially adverse condition 2, this steam condenses a short distance from the waste disposal containers. The effects of heat and water on the mechanical response of the Topopah Spring Member are under study. The opening, closing, or creation of fractures around the repository is not expected to affect steady-state percolation rates, because very little fracture flow is expected in the repository host rock at the upper bound on flux of 0.5 millimeter (0.02 inch) per year (Wilson, 1985).

Conclusion

A preliminary analysis of the Yucca Mountain site indicates that the present and expected characteristics of the host rock and the surrounding units will permit compliance with the requirements specified in 10 CFR 960.4-1 (1984) and 10 CFR 60.113 (1983). Furthermore, as reviewed in Section 6.4.2, the results of a preliminary performance analysis, using available rock-characteristics data and an upper bound on flux of 0.5 millimeter (0.02 inch) per year lend considerable confidence to the expectation that detailed site characterization will support preliminary results. Evidence to date indicates that the engineered barrier system will limit radionuclide releases to less than 1 part in 100,000 of the 1,000-year inventory. No potential interactions among the waste, host rock, ground water, and engineered components that could compromise waste isolation have been identified. Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition for postclosure rock characteristics (level 3).

6.3.1.3.6 Plans for site characterization

A number of tests are planned to supplement the existing rock characteristics data base. Overcore tests to determine in situ stresses in Yucca

Mountain will be performed at three levels during construction of the exploratory shaft. An enhanced heated block experiment is planned for exploratory-shaft in situ testing to determine the rock response to induced stress and thermal changes. Permeability changes in selected fractures under various stress and thermal loads will also be measured. A large-scale-heater experiment will be conducted to evaluate the near field rock response to waste-imposed thermal loads. Thermal, thermomechanical, and hydrothermal measurements will be made and used to establish the behavior of the host rock to be expected after repository closure, particularly with regard to any possible thermal effects on retardation.

6.3.1.4 Climatic changes (10 CFR 960.4-2-4)

6.3.1.4.1 Introduction

The qualifying condition for this guideline is as follows:

The site shall be located where future climatic conditions will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.

Climatic changes could, over time, alter the geohydrologic system at a site. This postclosure guideline on climatic changes is concerned with changes that may favorably or unfavorably affect the ability of a repository to isolate waste after closure.

The guideline consists of two favorable conditions, two potentially adverse conditions, and one qualifying condition. The evaluations presented below are summarized in Table 6-30.

6.3.1.4.2 Data relevant to the evaluation

The climates of the Nevada Test Site and its vicinity during the last 45,000 years have been reconstructed (Spaulding, 1983; Spaulding et al., 1984) largely on the evidence of plant macrofossils found in the middens of pack rats (genus *Neotoma*). These authors also review the literature on global and regional climatic changes and predict future climatic variations. Thompson and Mead (1982) also examined pack-rat middens and found the presence of subalpine and boreal mammals at relatively low elevations during the late Wisconsin.

Uplift of the Sierra Nevada and Transverse ranges may have long-term effects on the climate of Nevada. During the Quaternary, increasing aridity in Nevada has been attributed to this uplift (Winograd et al., 1985). Estimates of the uplift of the Sierra Nevada are discussed in Huber (1981) and Hay (1976).

Table 6-30. Summary of analyses for Section 6.3.1.4; climatic changes (10 CFR 960.4-2-4)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITIONS	
(1) A surface-water system such that expected climatic cycles over the next 100,000 years would not adversely affect waste isolation.	The evidence indicates that this favorable condition is present at Yucca Mountain: regional and site surface-water systems probably have been the same for several-hundred thousand years; expected climatic changes will not significantly change surface water systems.
(2) A geologic setting in which climatic changes have had little effect on the hydrologic system throughout the Quaternary Period.	The evidence indicates that this favorable condition is not present at Yucca Mountain: Quaternary climates were probably not substantially different from modern climates; however, increased flux and higher water tables probably occurred within the geologic setting during the Quaternary Period.
POTENTIALLY ADVERSE CONDITIONS	
(1) Evidence that the water table could rise sufficiently over the next 10,000 years to saturate the underground facility in a previously unsaturated host rock.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: there is no evidence that the water table was ever as high as the proposed repository level; climatic changes are not expected to cause sufficient water-table rise to flood the repository.
(2) Evidence that climatic changes over the next 10,000 years could cause perturbations in the hydraulic gradient, the hydraulic conductivity, the effective porosity, or the groundwater flux through the host rock and surrounding geohydrologic units, sufficient to significantly increase the transport of radionuclides to the accessible environment.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: increased precipitation could increase unsaturated zone flux, but major changes in hydraulic conditions are not expected over the next 10,000 years. If flux in the host rock was much higher than present, the site would still be expected to meet EPA limits at the accessible environment in 10,000 years.

Table 6-30. Summary of analyses for Section 6.3.1.4; climatic changes (10 CFR 960.4-2-4) (continued)

Condition	Department of Energy (DOE) finding
QUALIFYING CONDITION	
The site shall be located where future climatic conditions will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.	Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): expected climatic changes will not cause significant changes in surface drainage; unsaturated-zone flux may increase, and the water-table altitude may rise, but radionuclide releases are not likely to exceed the release limits.

Regional hydrology was described by Winograd and Thordarson (1975). Ground-water flow systems in the vicinity of Yucca Mountain were investigated by Czarnecki and Waddell (1984). Site-specific hydrologic data are presented by Thordarson (1983) and Robison (1984). Current precipitation data for nearby areas are presented in Quiring (1983).

There are also some data and interpretations about Pleistocene water-table levels, ground-water recharge, and pluvial lake formation in areas adjacent to Yucca Mountain. Winograd et al. (1983) described the late-Pleistocene hydrologic conditions of the Ash Meadows ground-water basin; their interpretation is based on the distribution of calcite veins in alluvium and lake beds, as well as fossil spring deposits of tufa. The mineralogy of the fine portion of the matrix samples of alluvium, taken from boreholes north of Frenchman Flat, suggests long-term stability of water-table levels during the Quaternary Period (Jones, 1982).

Climatic changes resulting in pluvial conditions would have affected the hydrologic system during the Quaternary. Effects of increased recharge on the water-table altitude were modeled by Czarnecki (1985) using a two-dimensional, finite-element ground-water flow model. Work done by Travis et al. (1984) indicates that pluvial conditions are likely to increase ground-water travel times.

Another result of a rise in the ground-water table could be the alteration of the vitric pumice (Hoover, 1968). Mineralogy and petrology of Yucca Mountain tuffs are discussed by Bish et al. (1984).

The mechanisms of recharge in the west central Amargosa Desert between 17,000 and 9,000 years ago have been inferred by Claassen (1983) from carbon, hydrogen, and oxygen isotope data. Evidence for pluvial lakes in Nevada during the last glacial episode has been interpreted by Mifflin and Wheat (1979). Lacustrine deposits in the Amargosa Valley and Crater Flat areas are considered to be Quaternary-Tertiary in age by Hoover et al. (1981) and Swadley (1983).

Assumptions and data uncertainties

The evidence that would allow reliable reconstructions of early to middle Pleistocene climates at Yucca Mountain is limited because of the absence of glacial deposits in the area and the incompleteness of the pedologic and geologic records. Consequently, it is assumed that the climatic extremes inferred from evidence of late Wisconsin age (Spaulding, 1983; Spaulding et al., 1984) would be typical of all Quaternary time. Predictions of the nature of future climatic changes were also made for some of the analyses in this section. The uncertainties implicit in these predictions are not quantifiable but are probably large, and the predictions are useful only for establishing reasonable bounds on estimates of climatic parameters.

The late-Pleistocene reconstruction of the Ash Meadows ground-water basin by Winograd and Doty (1980) does not specifically apply to Yucca Mountain because the latter is in the Alkali Flat-Furnace Creek Ranch ground-water basin (Waddell, 1982). However, the reconstructions developed for the

Ash Meadows basin should be generally applicable to ground-water basins in the Death Valley ground-water system. No definitive evidence of Quaternary water levels has been found during preliminary investigation of tuff minerals from Yucca Mountain (see geochemistry favorable condition 1, Section 6.3.1.2). The effects of pluvial conditions on flow paths and water levels beneath Yucca Mountain are being studied with mathematical models of the regional and local hydraulic systems.

Current understanding of the relation between precipitation and recharge to the water table beneath Yucca Mountain is discussed in Section 6.3.1.1.5, where a value of 0.5 millimeter (0.02 inch) per year is justified as an upper bound on local recharge to the water table beneath Yucca Mountain. Conceptual models of flow in the unsaturated zone are not yet sufficiently developed to permit quantitative testing of the relations among precipitation, net infiltration, percolation, and recharge. Analyses of the effects on waste isolation of climatic changes made to date are largely qualitative. When quantitative analyses are made, they will rely heavily on preliminary performance analyses and on preliminary analyses of system-parameter sensitivities. Preliminary performance analyses and parameter studies will be updated as data on the site are acquired. The first available versions are summarized in Section 6.4.2 and in Sinnock et al. (1984).

6.3.1.4.3 Favorable conditions

(1) A surface-water system such that expected climatic cycles over the next 100,000 years would not adversely affect waste isolation.

Evaluation

Because past geohydrologic events and processes are probably the best indicators of future conditions, a discussion of the regional climate during the Quaternary is included in the evaluation of this favorable condition. Pluvial climates probably had little effect on the principal surface-water features of the region. By early Quaternary time, lakes of Tertiary age that had existed in the Amargosa Valley and Crater Flat areas had disappeared, although the range of ages of the associated lacustrine deposits is not well known. These deposits are considered to be Quaternary-Tertiary in age by Hoover et al. (1981) and Swadley (1983). According to the reconnaissance studies of Mifflin and Wheat (1979), the pluvial climates that periodically occurred during the remainder of the Quaternary did not cause perennial lakes to form in southern Nevada, like those that existed in central and northern Nevada.

Surface-water drainage basins in the Yucca Mountain region were probably well established by early Quaternary time, and the closed surface-water and ground-water basins that exist today existed throughout the Quaternary. Although Lake Amargosa may have continued into early Quaternary, throughout most of this period the Amargosa River drainage system was integrated with Death Valley. The tributary Fortymile Wash drainage system and the bedrock washes dissecting Yucca Mountain and other ranges were also established by

early Quaternary time. In a process that continues today, numerous small shifts in the positions of channels of ephemeral washes occurred during the Quaternary, as shown by the distribution of various types of Quaternary alluvial deposits (Hoover et al., 1981).

Deep entrenchment, low rates of erosion, and present topographic divides make it unlikely that the largest probable climatic change, from arid to semiarid, would cause a significant change in the location or the size of the drainage system at Yucca Mountain. Such climatic changes would not produce long-term water impoundments closer than Death Valley, which is 30 to 40 kilometers (20 to 25 miles) away.

There is no evidence at Yucca Mountain of surface-water impoundments formed by landslides. Eolian sands may have clogged some drainages at Yucca Mountain during early Quaternary time, but such sands are very permeable and also easily eroded. No evidence of water impoundment by eolian sands is known.

Conclusion

Surface-water systems in the region and at the Yucca Mountain site have changed little during at least the last several hundred thousand years of the Quaternary Period. The expected effects of predicted climatic changes on geohydrologic processes are not significant; no new water impoundments (lakes) nor significant changes in surface drainage are expected. No adverse effects on waste isolation are likely to result from climatic changes in the surface-water systems in the next 100,000 years. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(2) A geologic setting in which climatic changes have had little effect on the hydrologic system throughout the Quaternary Period.

Evaluation

Evidence of climatic changes during the Quaternary comes from the geologic and plant-fossil records. A variety of types of deposits of Quaternary age occur in the region, including debris flows, fluvial sand sheets, eolian dunes, and coarse fluvial deposits (Hoover et al., 1981; Swadley, 1983). These units represent various environments of deposition that in turn reflect, in part, fluctuating climatic conditions. Although specific climates cannot be defined, the evidence is consistent with an arid to semiarid climate (Hoover et al., 1981). In addition, climatic changes can be inferred from the development of various landforms and rocks in the area and from the occurrence of three regional unconformities.

Vegetative covers varied in type during the past 45,000 years, as indicated by variations in the assemblages of plant macrofossils contained in pack-rat middens. These variations reflect changes in climate, in the sense that the assemblages are indicators of the effective moisture available at the time the plants were growing. Examinations of pack-rat middens show that, at different times during the last 45,000 years, the regional vegetative cover varied from a well-developed juniper woodland to modern desert scrub at intermediate elevations of about 1,200 to 1,800 meters (4,000 to 6,000 feet), and from a subalpine conifer woodland, to a pinyon-juniper

woodland, and to a woodland-desert scrub mosaic at higher elevations above 1,800 meters (6,000 feet) (Spaulding, 1983).

Evaluation for pluvial climates

Quaternary hydrologic conditions that differed the most from modern conditions probably were those that occurred during several pluvial periods of presumably wetter conditions. These pluvials alternated with interpluvials, periods during which climatic and hydrologic conditions were similar to those of today. Most evidence for estimating the nature of pluvial climates in the region is based on pluvials of late Wisconsin age; in southern Nevada, there is virtually no evidence for estimating early Wisconsin and pre-Wisconsin paleoclimates, except for the qualitative evidence of landforms, paleosols, and unconformities. Therefore, the reconstruction of climates that existed before late Wisconsin time in southern Nevada is tenuous. However, some evidence indicates that the climate in Nevada during each of the pluvials was similar; therefore, an analysis of the late Wisconsin pluvial climates and their hydrologic effects provides a sound basis for estimating the maximum effects that occurred during the entire Quaternary. For example, on a global scale, similar climatic conditions probably prevailed during each of the major glacial epochs that occurred during the Quaternary (Spaulding, 1983). Mifflin and Wheat (1979) suggest that the pluvial lakes of Lahontan (Wisconsin) age that occurred in central and northern Nevada were generally as large as the lakes of pre-Lahontan times. This suggestion is based primarily on the absence of evidence of older lake shorelines at higher elevations (although such evidence may have been destroyed by erosion). On the other hand, the latest Wisconsin pluvial is believed to have been wetter and warmer than the one that preceded it during the Wisconsin full-glacial time (Spaulding et al., 1984). Because of the higher temperatures, greater precipitation would have been required to maintain lake levels at elevations similar to those at which lakes occurred during earlier, cooler pluvials.

Winograd et al. (1985) hypothesize that a progressive and continued uplift of the Sierra Nevada and Transverse ranges during the Quaternary may have led to a long-term trend of increasing aridity in Nevada. Huber (1981) suggests that the Sierra Nevada have risen about 1,000 meters (3,300 feet) since the Pliocene, and Hay (1976) postulates a rise of 1,800 meters (5,900 feet) in the last 4.5 million years. The rising mountain ranges would have produced a rainshadow effect that would have modified the distribution and the amount of precipitation in Nevada and resulted in increasing aridity (Winograd et al., 1985).

Most investigators believe that, even during pluvials, semiarid conditions persisted on the valley floors of southern Nevada and that conditions no wetter than subhumid prevailed on the highest mountains (Winograd and Doty, 1980; Thompson and Mead, 1982; Spaulding et al., 1984; and Mifflin and Wheat, 1979). A review of literature relevant to pluvial climates in southern Nevada and studies of pack-rat middens in the region indicates that, at the time of the global glacial maximum during late Wisconsin time (18,000 $\pm$ 3,000 years ago), temperatures in the region averaged 6 to 7°C (11 to 13°F) below the modern mean annual temperature (Spaulding, 1983; Spaulding et al., 1984). Average annual precipitation was probably 20 to 30 percent above the modern value. Winter precipitation was 60 to 70 percent above the modern average, while summer precipitation was 40 to 50 percent below. Mifflin and

Wheat (1979) also concluded that full-pluvial climates in Nevada did not differ greatly from modern climates. From the results of climatologic and hydrologic analyses, they estimate that the statewide full-pluvial mean annual temperature was about 3°C (5°F) lower and the mean annual precipitation was about 68 percent higher than modern values; they further conclude that the absence of physiographic evidence of pluvial lakes in southern Nevada supports the concept of aridity in that area during pluvial climates.

Although the estimated departures from modern annual and seasonal precipitation may appear substantial on a percentage basis, they are minor when calculated on an absolute basis. If the percentage departures presented by Spaulding (1983) are applied to estimates of the average precipitation for 1964 through 1981 at an elevation of 1,200 meters (4,000 feet) in the vicinity of Yucca Mountain, the estimated precipitation for full-glacial near-pluvial conditions is as follows:

	<u>Estimated precipitation, mm (in.)</u>	
	<u>1964-1981</u>	<u>Near-pluvial</u>
Annual	150 (5.9)	195-210 (7.7-8.3)
Cool season (Oct.-Apr.)	108 (4.2)	173-184 (6.8-7.2)
Warm season (May-Sep.)	42 (1.6)	21-25 (0.8-1)

The estimates for 1964-1981 are based on maps presented by Quiring (1983).

After the full-glacial (Wisconsin-maximum) pluvial, a trend toward warmer and drier conditions began (Spaulding et al., 1984). The drying trend was interrupted by a pluvial period that occurred during the latest Wisconsin time (12,000 to 10,000 years ago) and early Holocene (10,000 to 8,000 years ago) times. The climate during this pluvial probably differed substantially from the preceding full-glacial pluvial and from modern conditions. Compared with conditions during the Wisconsin maximum, the average annual temperatures during the latest Wisconsin pluvial were 4 to 6°C (7 to 11°F) higher, and the average annual precipitation was probably greater. The greater rainfall occurred during both the winter and the summer half years. Compared with modern conditions, average annual temperatures were probably only about 2°C (4°F) lower, and the average annual precipitation may have been as much as 100 percent greater. These conclusions are based on the distributions of vegetation assemblages during the late Wisconsin and early Holocene; they are consistent with predictions of climatic change and with evidence of fluctuations of lake levels in the Great Basin (Spaulding et al., 1984).

If precipitation during the latest Wisconsin pluvial had been 100 percent greater than modern, the average annual precipitation at that time would have been about 300 millimeters (11.8 inches). Such a relatively high rainfall would have been required to maintain the high stands of Searles Lake and Lake Lahonton under the warm (near-modern) average temperature that probably prevailed (Spaulding et al., 1984). This estimate of the precipitation increase is the highest of any reported in the studies reviewed by Spaulding

(1983) or identified elsewhere. Thus, it provides a conservative estimate that can be used to examine potential climatic effects on the hydrologic system at Yucca Mountain.

Evaluation for hydrologic effects

Climatic changes resulting in pluvial conditions during the Quaternary probably had the following effects on the hydrologic system: increased recharge, increased altitude and gradients of the water table; upgradient shifts in discharge points; and changes in surface-water drainage systems. Field evidence in the immediate vicinity of Yucca Mountain is not yet available to determine the size of these effects.

During the pluvial climates of the Quaternary, ground-water recharge rates were probably higher than modern rates. Claassen (1983) reports that carbon, hydrogen, and oxygen isotope data indicate that major recharge occurred in the area at the end of Pleistocene and through early Holocene time. Probably the recharge came principally from snowmelt and occurred as downward infiltration of surface runoff in major washes (Claassen, 1983), such as Fortymile Wash. During the span of this recharge period, two distinct climatic changes occurred, one at about the Wisconsin maximum (18,000 $\pm$ 3,000 years ago) and one in the latest Wisconsin (12,000 to 10,000 years ago) (Spaulding et al., 1984). The specific pluvial climatic conditions in the Yucca Mountain area that resulted in these recharge conditions are being evaluated by analyzing plant macrofossils in pack-rat middens in the area.

An increase in ground-water recharge would have been accompanied by increases in moisture flux through the unsaturated zone in some portions of the ground-water basin. The mechanisms and controls on the rates and distribution of recharge are not well known, either for modern or for pluvial conditions; therefore, the magnitudes of recharge during the last half of the late Wisconsin are not known at this time, but they may have been substantially greater than those of modern recharge (Czarnecki, 1985). Investigations to assess this condition are underway.

The increased flux may have been sufficient to affect the potential for developing perched-water conditions in the unsaturated zone and to modify the hydrologic system in the underlying saturated zone. However, hydrologic tests and measurements of core samples of unsaturated rock units underlying Yucca Mountain indicate that the fracture and matrix permeability is generally high enough to transmit water not only at the low modern fluxes (less than 0.5 millimeter (0.02 inch) per year, as discussed in Section 6.3.1.1), but also at the higher fluxes postulated for pluvial times. Thus, the increase in recharge that is postulated for pluvial climates may not have affected significantly the potential for developing perched-water conditions. However, it is likely that the increased flux may have affected the hydrologic conditions in the saturated zone (see evaluation of potentially adverse condition 2).

An evaluation of the effects of Quaternary climatic changes on the altitude of the water table is difficult, because tectonic and erosional as well as climatic factors could have affected the position of the water table.

Some evidence of Quaternary hydrologic conditions is found in the region around Yucca Mountain. Even though the evidence is generally not within the flow system underlying Yucca Mountain, the interpretations from this evidence can be used as general indicators of the effects of Quaternary climatic changes on the regional hydrologic systems, as described in the following paragraphs.

Jones (1982) examined cores of fine-grained alluvium from a borehole in Frenchman Flat (located in the Ash Meadows ground-water basin) for mineralogic evidence of former higher water tables. In the interval 0 to 50 meters (0 to 165 feet) above the present water table, the alluvium contains an abundance of zeolites and smectite clays with expanded basal spacings and relatively uniform clay hydration properties. These conditions suggest possible former saturation, but they may also be related to differences in the primary environments of deposition. Jones (1982) concludes that the relative uniformity of clay hydration is consistent with an interpretation that the water table has been within approximately 50 meters (165 feet) of its present position for a long time, perhaps throughout most of the Quaternary.

Death Valley and the Amargosa Desert are the principal discharge areas for both the Ash Meadows ground-water basin and the Alkali Flat-Furnace Creek Ranch ground-water basin (Winograd and Thordarson, 1975; and Waddell, 1982) as shown in Figure 6-17. Winograd et al. (1983) reported that calcite veins in the Ash Meadows discharge area have been estimated to be 0.8 to 1 million years old by uranium-thorium dating techniques. Thus, these regions probably were ground-water discharge areas during most of the Quaternary. Within the Ash Meadows ground-water basin, however, discharge from the carbonate aquifer occurred as much as 14 kilometers (9 miles) northeast (up gradient) of the modern discharge line during the Pleistocene, and the water table may have been 50 meters (165 feet) higher than its present elevation (Winograd and Doty, 1980). In central Frenchman Flat, 58 kilometers (36 miles) northeast of Ash Meadows, the maximum water-table elevation in the carbonate aquifer probably did not exceed 30 meters (100 feet) above the modern level (Winograd and Doty, 1980). This estimate, based on theoretical studies, is consistent with the 50-meter (165-foot) maximum increase estimated in the Devils Hole area of the Ash Meadows ground-water basin. Preliminary modeling indicates that during pluvials, similar upgradient discharge points and increased water table altitudes could develop in the future in the Alkali Flat-Furnace Creek Ranch ground-water basin in which the Yucca Mountain site is located (Czarnecki, 1985).

Quaternary climatic changes probably produced cyclic fluctuations in both the altitude of the water table and the positions of the ground-water discharge points of the Ash Meadows basin, but Winograd and Doty (1980) postulate a net direction of change in both of these hydrologic conditions during the Pleistocene Epoch. They suggest that the highest water-table position occurred in the early Pleistocene and that a net downgradient migration of discharge sites and a net decline of the water table occurred from early to late Pleistocene time. They attribute these changes to the progressive integration of the Amargosa Valley and the Death Valley watersheds, coupled with periodic faulting along the modern spring lineament in Ash Meadows. A long-term trend of increasing aridity, if it occurred,

Figure 6-17. Location of Yucca Mountain site with respect to the relevant basins of the Death Valley ground-water system. The Amargosa Desert ground-water basin is a governmentally administrated area designated by the State engineer in order to prevent over appropriation of ground-water resources. Modified from Waddell (1982) and information from the State of Nevada.

could also have contributed to these hydrologic changes. Similar changes would be expected to have occurred in the Alkali Flat-Furnace Creek Ranch ground-water basin.

In the tuff and alluvium of the Alkali Flat-Furnace Creek Ranch ground-water basin, no direct evidence has been observed for a water table that was higher during the Quaternary than it is now. Depth to water in the Yucca Mountain area is generally 500 to 750 meters (1,650 to 2,450 feet) (Robison, 1984). To estimate the effects of increased recharge on the altitude of the water table in the basin, a two-dimensional flow model (Czarnecki and Waddell, 1984) was modified and analyzed at various recharge rates. According to Czarnecki (1985), preliminary modeling has been able to simulate a maximum rise in water-table altitude within the Alkali Flat-Furnace Creek Ranch ground-water basin of 130 meters (430 feet) during pluvial conditions. This value of 130 meters (430 feet) resulted from assuming a 100-percent increase in precipitation over Yucca Mountain (probable maximum increase in next 10,000 years) which in turn was assumed to produce a recharge rate of 7.5 millimeters per year (0.29 inches) beneath the primary repository area.

The prediction of a 130-meter (430-foot) rise in the water table at Yucca Mountain in response to a 100-percent increase in precipitation during a return to pluvial conditions (Czarnecki, 1985) is highly uncertain and may be very conservative. The use of a two-dimensional model to simulate three-dimensional flow and uncertainty in appropriate boundary conditions for modeling are inherent sources of uncertainty in predictions of water-table altitudes.

The amount of increase in precipitation during a full pluvial is uncertain. Spaulding (1983) indicated that in the most recent full pluvial, precipitation was probably on the order of .50 percent greater than modern amounts, while Spaulding et al. (1984) revised this estimate to 100 percent above the modern precipitation values. Czarnecki (1985) assumed that a precipitation increase of 100 percent would cause recharge to increase by a factor of 15. To examine the accuracy of this assumption, modeled recharge estimates were compared to field measurements of recharge in an area with altitudes that are similar to Yucca Mountain and precipitation about 100 percent greater than that at Yucca Mountain today. This comparison suggests that the recharge estimates for Yucca Mountain may be too high by about two-thirds due to runoff (Czarnecki, 1985). No correction for runoff was applied to the recharge estimates for the preliminary predictions of water-table changes at Yucca Mountain; the effect would be to decrease the effective recharge to much less than the computed volumes used in the analyses (Czarnecki, 1985).

Another source of uncertainty in the simulation of water-table changes during a pluvial period is the method used to simulate recharge in the modeled area. The largest baseline fluxes were assigned at the northern boundary of the modeled area and along Fortymile Wash. The flux multiplier of 15 times baseline flux was applied simultaneously to all areas.

Sensitivity studies by Czarnecki (1985), show that the resulting change in water-table position beneath the primary repository area was primarily caused by the increased flux simulated by applying the multiplier at Fortymile Wash. Although it is true that washes are likely to be sources of major recharge during wetter climatic periods, applying the same recharge multiplier over the entire modeled area is probably overly conservative because uplands are unlikely to experience increased infiltration relative to precipitation in the same proportion as washes.

A final source of uncertainty on the modeling of water-table rise is related to the system response time. The Czarnecki (1985) model is not time dependent; it implicitly assumes that recharge is instantaneous and that water-table response is instantaneous. The rate at which the water-table altitude would change in response to increased precipitation is unknown. This suggests that with the onset of a pluvial, it is uncertain how long it would take for changes in water-table altitude to occur.

With all of the above uncertainty on the effects of climatic changes on the hydrologic system, a conservative position is warranted for this favorable condition.

Conclusion

Yucca Mountain is in a geologic setting in which the maximum departures from modern climatic conditions during most of the Quaternary were probably not substantial. However, changes in the water-table altitude and possible modifications of flow paths to discharge areas cannot be ruled out. Therefore, the evidence indicates that this favorable condition is not present at Yucca Mountain.

6.3.1.4.4 Potentially adverse conditions

- (1) Evidence that the water table could rise sufficiently over the next 10,000 years to saturate the underground facility in a previously unsaturated host rock.

Evaluation

Several lines of evidence indicate that the water table will not rise enough during the next 10,000 years to saturate a repository in the Topopah Spring welded unit beneath Yucca Mountain. Climatic changes and their effects on the regional ground-water system are discussed under favorable condition 2. The discussion that follows addresses the potential for a water-table rise beneath Yucca Mountain.

The proposed repository is closest to the water table at its northeastern edge. Here, the repository would be at an elevation of approximately 915 meters (3,000 feet), or approximately 185 meters (605 feet) above the present water table (altitude 730 meters (2,395 feet)). Therefore, the water table would have to rise about 185 meters (605 feet) before any part of the

proposed repository would be flooded. As discussed in favorable condition 2, flow modeling (Czarnecki and Waddell, 1984; Czarnecki, 1985) suggests that the maximum rise in water-table altitudes during pluvial conditions is unlikely to exceed 130 meters (430 feet). Even if extreme pluvial conditions developed, the additional 55 meters (180 feet) should provide adequate assurance that the repository could not become saturated. It should also be noted that the repository midplane dips to the east so that the 185-meter (605-foot) distance is a minimum thickness for the unsaturated zone beneath the repository. Figure 6-4(A) in Section 6.3.1.1 shows that the average distance from the repository to the water table is about 250 meters (820 feet). In addition, Winograd et al. (1985) suggest there may be a long-term trend toward increasing aridity in the Yucca Mountain area.

Vitric pumice does not remain unaltered for long periods of time in the saturated zone (Hoover, 1968). Beneath the central portion of Yucca Mountain, nonwelded tuffs containing abundant vitric pumice occur at altitudes that range from 120 meters (400 feet) at boreholes USW H-5 and USW G-4 to 250 meters (820 feet) at borehole USW H-3 above the present water table. These altitudes are 24 to 120 meters (80 to 400 feet) below the repository horizon (Bish et al., 1984). Therefore, the rocks in the repository horizon were probably never below the water table, at least not for any substantial length of time.

The hydraulic conductivity of the densely welded, saturated Topopah Spring Member beneath Fortymile Wash is relatively high, approximately 1 meter (3.3 feet) per day (Thordarson, 1983) and may partly account for the very low hydraulic gradient in the saturated zone between Yucca Mountain and Fortymile Wash. An increase in recharge would cause an increase in hydraulic gradient approximately proportional to the increase in recharge; the gradient would be partly controlled by the distance to the discharge area. In areas where the gradient is now low, an increase in gradient would result in only small increases in hydraulic heads. In the Yucca Mountain area, the altitude of the water table is about the same (within 0.5 meter (1.6 feet) as the composite hydraulic potential of the upper few hundred meters of the saturated zone (Robison, 1984); the hydraulic potential may therefore be equated with the position of the water table.

An alternative approach for estimating potential changes in altitude of the water table is based on the following reasoning. In the discharge area near Alkali Flat and upgradient, the water table is within a few meters of the land surface. Therefore, a small increase in the hydraulic gradient would cause springs to develop upgradient. Approximately 15 kilometers (9.5 miles) north of Death Valley Junction, the hydraulic gradient is greater than it is immediately up and down gradient, which indicates rocks of lower permeability in this area. Springs would develop upgradient of this area if recharge increased appreciably, thereby permitting water to leave the ground-water system. If recharge increased enough (for example, three to four times the present rate) to cause springs to develop in these potential discharge areas (altitude 760 meters (2493 feet)), the water-level altitude at Well J-12 could be expected to increase in time to between 790 and 825 meters (2,590 and 2,700 feet). Because of the high transmissivity in western

Jackass Flats, the water level beneath most of the repository would also be 800 to 825 meters (2,625 to 2,707 feet), but the lowest part of the repository is estimated to be more than 900 meters (2,950 feet) above sea level.

Conclusion

There is no evidence that the water table was as high as the proposed repository level during the Quaternary Period, and it is very unlikely that climatic changes during the next 10,000 years could cause the water table to rise sufficiently to saturate the underground facility. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(2) Evidence that climatic changes over the next 10,000 years could cause perturbations in the hydraulic gradient, the hydraulic conductivity, the effective porosity, or the ground-water flux through the host rock and surrounding geohydrologic units, sufficient to significantly increase the transport of radionuclides to the accessible environment.

Evaluation

Likely climatic changes over the next 10,000 years probably would be driven by increases in the global atmospheric concentration of carbon dioxide and by changes in the earth's orbit. In the near future Yucca Mountain might experience summer temperatures at least 3°C (5°F) higher and summer rainfall as much as 100 percent higher than today's value (Spaulding et al., 1984); these changes could be caused by increases in carbon dioxide concentrations. On the other hand, changes in the earth's orbit could eventually override the effects of carbon dioxide and lead to a glacial stage in about 23,000 years and culminate in a glacial maximum about 60,000 years into the future (Spaulding, 1983). Pluvial conditions, which may coincide with the glacial stage, but do not necessarily do so, are considered possible within the next 10,000 years.

As explained in the evaluation of favorable condition 2, conservative and preliminary computer modeling results by Czarnecki (1985) simulated a maximum increase of about 130 meters (425 feet) in water-table altitudes below the repository during a pluvial period. The minimum distance between the repository midplane and the water table is presently 185 meters (605 feet) in the northeastern corner of the primary repository area (See Figure 6-4). Over most of the primary area, the water table is more than 250 meters (820 feet) below the repository midplane. The uncertainty in the prediction of the 130-meter (425-foot) water-table rise is reviewed in the second potentially adverse condition above.

Even with the onset of pluvial conditions soon after repository closure, the response time for changes in hydrologic conditions and increases in water table altitude is likely to provide a lag time of many hundreds, and perhaps thousands of years before a maximum water-table altitude could occur, no matter what that maximum altitude would be. Furthermore, the retardation mechanisms that would be effective in both the saturated and unsaturated zone

under conditions of higher flux and predominantly fracture flow, are likely to provide a factor of 100 (Sinnock et al., 1984) and perhaps a factor of 400 (Travis et al., 1984) increase in travel times for radionuclides over ground-water travel times. This argument suggests that there is a very low probability that climate changes in the next 10,000 years could be sufficient to induce significant increases in transport of radionuclides to the accessible environment.

Conclusion

The climatic changes that are possible during the next 10,000 years at Yucca Mountain may cause changes in the hydraulic gradient; changes in flux could alter the moisture content in the unsaturated hydrogeologic units; particle velocities in both the saturated and the unsaturated zones could increase if flux is greater; and the water-table altitude may increase. The extent of these changes is uncertain. However, these changes are not likely to significantly increase the transport of radionuclides to the accessible environment. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

6.3.1.4.5 Evaluation and conclusion for the climate changes qualifying condition

Evaluation

The effects of predicted climatic changes on geohydrologic processes are not expected to be large; no new lakes or significant changes in surface drainage are expected. Climatic conditions during most of the Quaternary Period probably did not depart substantially from modern conditions and probably had minor effects on the main features of the present hydrologic system. There is no evidence that the water table was as high as the proposed repository level during the Quaternary Period, and it is extremely unlikely that the water table will rise sufficiently to saturate the repository in the next 10,000 years. Considering the most extreme pluvial conditions and the maximum increase in water-table altitude beneath the repository, radionuclide travel times from the disturbed zone to the accessible environment should still be a factor of at least 100, and perhaps 400 longer than the ground-water travel times. This retardation estimate relies only on matrix diffusion as an agent for retarding radionuclide transport. It appears likely that the Yucca Mountain site will comply with the U.S. Environmental Protection Agency release limits under all possible climatic changes over the next 10,000 years.

Conclusion

Future climatic conditions during the next 10,000 years would not be likely to lead to radionuclide releases from a repository at Yucca Mountain greater than those allowable under the requirements specified in the post-closure system guideline (10 CFR 960.4-1, 1984). Therefore, on the basis of

the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition for postclosure climatic changes (level 3).

6.3.1.4.6 Plans for site characterization

Computer modeling efforts will be continued to gain a better understanding of factors controlling water-table altitudes in the Alkali Flat-Furnace Creek Ranch ground-water basin. Paleohydrologic, paleoclimatologic, and geologic studies will focus on the Yucca Mountain site to determine whether conclusive evidence for past water-table positions can be obtained. Further evolution of the conceptual model for flow in the unsaturated zone will lead to an improved definition of the relationship between precipitation, percolation rate, and recharge.

6.3.1.5 Erosion (10 CFR 960.4-2-5)

6.3.1.5.1 Introduction

The qualifying condition for this guideline is as follows:

The site shall allow the underground facility to be placed at a depth such that erosional processes acting upon the surface will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.

The objective of the erosion guideline is to ensure that erosional processes will not degrade the waste-isolation capabilities of a repository site. In evaluating the potential effects of erosion on waste isolation, the thickness of overburden above the host rock is most important. The site should allow the underground facility to be placed deep enough to ensure that the repository will not be uncovered by erosion or otherwise adversely affected by surface processes.

The erosion guideline consists of three favorable conditions, two potentially adverse conditions, one disqualifying condition, and one qualifying condition. The evaluations reported below are summarized in Table 6-31 for all conditions except the disqualifying condition.

6.3.1.5.2 Data relevant to the evaluation

Summary of available data

The surficial geology of the Yucca Mountain area has been mapped (Scott and Bonk, 1984) from which the nature of erosional processes operating during the Quaternary Period can be interpreted. Measurements of the depth of stream incision in dated alluvial deposits and in tuff in the vicinity of Yucca Mountain have been made, and the maximum rates of stream incision have been calculated (USGS, 1984). Average erosion rates for Yucca Mountain

Table 6-31. Summary of analyses for Section 6.3.1.5; erosion (10 CFR 960.4-2-5)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITIONS	
(1) Site conditions that permit the emplacement of waste at a depth of at least 300 meters below the directly overlying ground surface.	The evidence indicates that this favorable condition is not present at Yucca Mountain: the preferred repository horizon cannot accommodate all waste at depths greater than 300 meters within the primary repository area.
(2) A geologic setting where the nature and rates of the erosional processes that have been operating during the Quaternary Period are predicted to have less than one chance in 10,000 over the next 10,000 years of leading to releases of radionuclides to the accessible environment.	The evidence indicates that this favorable condition is present at Yucca Mountain: minimum depth to the repository is about 230 meters; there is only one chance in 10,000 of removing 5.5 meters (18 feet) of overburden in 10,000 years. Erosional processes are not expected to affect waste containment and isolation.
(3) Site conditions such that waste exhumation would not be expected to occur during the first one million years after repository closure.	The evidence indicates that this favorable condition is present at Yucca Mountain: a waste repository in Yucca Mountain would not be exhumed during the first one million years at the fastest credible erosion rate.
POTENTIALLY ADVERSE CONDITIONS	
(1) A geologic setting that shows evidence of extreme erosion during the Quaternary Period.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: there is no observed evidence of extreme stream incision rates during the past 300,000 years; little change has been observed in Quaternary erosional processes.

Table 6-31. Summary of analyses for Section 6.3.1.5; erosion (10 CFR 960.4-2-5) (continued)

Condition	Department of Energy (DOE) finding
(2) A geologic setting where the nature and rates of geomorphic processes that have been operating during the Quaternary Period could, during the first 10,000 years after closure, adversely affect the ability of the geologic repository to isolate the waste.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: no credible geomorphic process has been identified that could be expected to adversely affect the isolation capabilities of the proposed site in the next 10,000 years.
QUALIFYING CONDITION	
The site shall allow the underground facility to be placed at a depth such that erosional processes acting upon the surface will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.	Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): erosional rates and processes at Yucca Mountain during the Quaternary Period are expected to continue; about 2 million years is the minimum credible time to exhume the repository.

during the Quaternary Period have not been determined, because the field data necessary for such calculations are not yet available. The potential host rock in the Topopah Spring Member has been identified (Johnstone et al., 1984) and the thickness of overburden has been analyzed (Mansure and Ortiz, 1984). Water-table altitudes are available from Robison (1984).

Assumptions and data uncertainties

In evaluating the site against this guideline, the rates of stream incision in alluvium and tuff are assumed to represent the average rates of vertical erosion for the tuffs at Yucca Mountain. This assumption leads to over estimates of the probability of exhumation by erosion because the average rates of vertical erosion will always be much lower than stream-incision rates. It is also assumed that the erosional rates and processes operating during the Quaternary Period will continue during the postclosure isolation period. This assumption appears valid because climatic conditions are not likely to change significantly (Section 6.3.1.4), and local uplift or subsidence is not likely to be significant (Section 6.3.1.7).

6.3.1.5.3 Favorable conditions

- (1) Site conditions that permit the emplacement of waste at a depth of at least 300 meters below the the directly overlying ground surface.

Evaluation

Figure 6-18 shows contours of the overburden thickness above the mid-plane of the repository envelope (45 meters (150 feet) thick) and the position of the cross section in Figure 6-19. Figure 6-19 shows profiles across Yucca Mountain at the 200- and 300-meter (656- and 984-foot) depths below the surface along an east-west cross section (Mansure and Ortiz, 1984). It also shows the depth of a plane representing the preferred horizon for the repository. This horizon is located in a portion of the densely welded Topopah Spring Member that contains less than 15 to 20 percent lithophysae and lies above the basal vitrophyre. In the primary area, on which site investigation has been focused, approximately 50 percent of the waste could be emplaced below 300 meters (984 feet). To emplace all the waste below 300 meters (984 feet) would require emplacement in the vitrophyre and lower units or the use of a higher thermal loading (i.e., placing the waste disposal containers closer together) than that currently used as a design basis. Other units deeper in Yucca Mountain have been considered as alternatives to the Topopah Spring Member (Johnstone et al., 1984).

Preliminary surface-mapping and borehole data suggest that the use of expansion areas adjacent to the primary area may allow the emplacement of additional waste below 300 meters (984 feet), while remaining within the part of the Topopah Spring Member that is relatively free of lithophysae (see Section 6.3.1.3, Figure 6-14). Further study of the areas adjacent to the primary area is necessary before their suitability can be established to the same degree of certainty that has been established for the primary area. There are no current plans to use the vitrophyre and the units below the Topopah Spring Member.

Figure 6-18. Contours of the overburden thickness above the midplane of the repository for primary repository area. See Figure 6-19 for cross section A-A'. Modified from Mansure and Ortiz (1984).

Figure 6-19. Profiles of the 200- and 300-meter (656- and 984-foot) depths below the surface of Yucca Mountain on schematic east-west cross section, labeled A-A' on Figure 6-18.

Conclusion

The data evaluated to date show that the potential host rock in the lower part of the Topopah Spring Member cannot accommodate all of the waste at depths greater than 300 meters (984 feet). Therefore, the evidence indicates that this favorable condition is not present at Yucca Mountain.

(2) A geologic setting where the nature and rates of the erosional processes that have been operating during the Quaternary Period are predicted to have less than one chance in 10,000 over the next 10,000 years of leading to releases of radionuclides to the accessible environment.

Evaluation

It is possible to postulate two mechanisms by which erosional processes operating at Yucca Mountain could adversely affect the potential for radionuclide releases to the accessible environment: (1) a gradual uncovering of the repository and (2) an alteration of the ground-water system.

The surface in the portion of the site that would contain the repository consists of densely to moderately welded tuff of the Tiva Canyon Member of the Paintbrush Tuff; the tuff dips 5 to 8° eastward, resulting in a relatively planar, eastward-sloping land surface. The welded tuff along the crest at the western edge of Yucca Mountain is resistant and essentially undissected by drainage channels, but to the east the Tiva Canyon Member is dissected by southeasterly draining channels with equilibrium profiles that are steeper than the dip of the tuff. Residual patches of the weakly consolidated Rainier Mesa Member of the Timber Mountain Tuff occur in the Tiva Canyon outcrop area (Scott and Bonk, 1984). Alluvium occurs in modern washes and fault valleys in the area.

The depth of stream incision has been measured by using dated stratigraphic horizons as reference points at several places in the vicinity of the site, and the maximum rate of incision has been estimated (USGS, 1984). Estimates based on two measurements in alluvium and one in the Tiva Canyon tuff show a mean rate of incision of 5×10^{-5} meter per year. The time spans represented by the measurements suggest that the average incision rate has been lower than 1×10^{-4} meter per year during the last 300,000 years. At a rate of 1×10^{-4} meter per year, erosion in the next 10,000 years would remove only 1 meter (3.3 feet) of overburden.

In order to affect hydrologic conditions in the vicinity of the site, erosion would have to cause a relocation of ground-water discharge to areas nearer to the repository site or expose rock units that would allow more infiltration. Erosion is unlikely to increase the potential for local infiltration, because the rocks in the overburden are already capable of passing fluxes well in excess of current and future percolation expected under the possible climatic changes during the next 10,000 years (favorable condition 2, Section 6.3.1.1). Therefore, at some locations all of the overburden that overlies the water table downgradient from the repository would have to be removed before the isolation potential of Yucca Mountain could be affected by

erosion. Within 5 kilometers (3 miles) downgradient of the repository, this would require the removal of about 280 meters (920 feet) of overburden (Robison, 1984). At a rate of 1×10^{-4} meter per year, the time for erosion to this depth would be 2.8 million years.

From another perspective, the removal of 280 meters (920 feet) of overburden to the depth of the water table in 10,000 years would require an erosion rate of about 2.8 centimeters (1.1 inches) per year, which exceeds any rate known to have occurred anywhere on earth over any 10,000-year period. Using the measurements of stream incision (USGS, 1984), the probability of removal of 280 meters (920 feet) of overburden in 10,000 years is less than 1 chance in 1,000,000. This probability was derived from the Student's t distribution, computed for a mean incision rate of 0.5 meter per 10,000 years and a standard deviation of 0.3 with 2 degrees of freedom. The same method gives 1 chance in 10,000 over 10,000 years of eroding to a depth of 5.5 meters (18 feet).

Conclusion

Average stream-incision rates have been lower than 1×10^{-4} meters per year for the last 300,000 years. If continued at this rate over the next 10,000 years, erosional processes would be expected to remove only 1 meter (3.3 feet) of overburden. This amount could not adversely affect waste containment and isolation. The probability of loss of isolation due to erosion is less than 1 chance in 1,000,000 over the next 10,000 years. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(3) Site conditions such that waste exhumation would not be expected to occur during the first one million years after repository closure.

Evaluation

The minimum thickness of the overburden above the underground facility is about 230 meters (750 feet) at the eastern edge of the primary repository area (see favorable condition 1). For about 50 percent of Yucca Mountain, the overburden is greater than 300 meters (984 feet). At an erosion rate of 1×10^{-4} meter per year, the time needed to uncover a repository at a minimum depth of 230 meters (750 feet) is 2.3 million years; for a depth of more than 300 meters (984 feet), it would take at least 3.0 million years.

Conclusion

If past average erosion rates continue in the future, a repository at Yucca Mountain would not be uncovered in the next 1 million years. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

6.3.1.5.4 Potentially adverse conditions

- (1) A geologic setting that shows evidence of extreme erosion during the Quaternary Period.

Evaluation

The measured maximum stream-incision rates in the vicinity of the site are between 2.2×10^{-5} and 8.2×10^{-5} meter per year; these maximum rates are inferred by measuring the depths of incision in Quaternary, and in some instances Tertiary surfaces 160,000 to 10 million years old. The mean of these rates is 5×10^{-5} meter per year, which is much lower than the 1×10^{-4} meter per year that is used in the evaluation of the qualifying condition and in favorable conditions 2 and 3. Modern denudation rates at the site are not considered extreme, and evidence indicates that there were few or no periods of extreme erosion at the site during the past 300,000 years.

Conclusion

Average stream-incision rates during the past 300,000 years were not extreme, and there was little change in the patterns of erosional processes at the site during the Quaternary Period. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

- (2) A geologic setting where the nature and rates of geomorphic processes that have been operating during the Quaternary Period could, during the first 10,000 years after closure, adversely affect the ability of the geologic repository to isolate the waste.

Evaluation

Geomorphic processes result when the combined effects of tectonic and climatic conditions create a local terrain that provides the potential energy for erosion. The rates of tectonism during the Quaternary are so low (Section 6.3.1.7) and the magnitudes of expected climatic changes are small enough (Section 6.3.1.4) that significant changes in geomorphic processes at Yucca Mountain are highly unlikely during the next 10,000 years. Because the estimated past and present rates of erosion have been shown to be incapable of affecting waste isolation for at least the next few million years, any credible change in these rates during the next 10,000 years would not adversely affect waste isolation.

Conclusion

No credible geomorphic process has been identified that could, in the next 10,000 years, adversely affect the isolation capabilities of the site. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

6.3.1.5.5 Disqualifying condition

The site shall be disqualified if site conditions do not allow all portions of the underground facility to be situated at least 200 meters below the directly overlying ground surface.

Evaluation

A repository at Yucca Mountain can be positioned so that all portions of the underground facility can be located below 200 meters (656 feet) and approximately 50 percent of the facility can be located at least 300 meters (984 feet) below the directly overlying ground surface (Mansure and Ortiz, 1984). The 200-meter (656-foot) overburden requirement is being used as a principal design constraint for locating the underground facility. According to stratigraphic data obtained during preliminary investigations at the Yucca Mountain site, the preferred interval of the densely welded tuff of the Topopah Spring Member (the zone with less than 20 percent lithophysae) is thick enough at depths greater than 200 meters (656 feet) to accommodate the underground facility (Figure 6-19).

Conclusion

The densely welded tuff of the Topopah Spring Member is sufficiently thick and deep for all portions of the underground facility to be located in the zone of low lithophysal content at least 200 meters (656 feet) below the directly overlying ground surface. Therefore, the evidence does not support a finding that the site is disqualified (level 1).

6.3.1.5.6 Qualifying condition

Evaluation

Geomorphic processes result from the combined effects of tectonic and climatic processes. The rates of tectonism are low (Section 6.3.1.7), and they are unlikely to induce changes in the erosional processes. As discussed in Section 6.3.1.4, the expected climatic changes are also unlikely to cause changes in erosional processes.

Measurements of stream-incision rates in the vicinity of Yucca Mountain suggest that the average incision rate has been lower than 1×10^{-4} meter per year during the last 300,000 years. The water table at some point down-gradient within 5 kilometers (3 miles) of the site would have to be uncovered by erosion before the isolation potential of Yucca Mountain could be affected. This would require the removal of about 280 meters (920 feet) of overburden, and, at expected erosion rates, would take about 2.8 million years. In the next 10,000 years, erosional processes are expected to remove only 1 meter (3.3 feet) of overburden from above the repository. Therefore, as shown by the measured depth of stream incision and dated alluvial materials, erosion could not uncover a repository at Yucca Mountain, nor could it alter the ground-water system sufficiently to adversely affect waste isolation.

For waste disposal in the unsaturated zone, the potential value of thick overburden should not be evaluated alone; equally important for an unsaturated zone repository may be the vertical distance from the repository to the water table. This thickness may bear more relationship to the waste-isolation capability of an unsaturated zone repository than does the thickness of the overburden.

Conclusion

The erosional rates and processes that have operated at Yucca Mountain during the Quaternary Period are very likely to continue for tens of thousands to millions of years into the future and will not adversely affect the waste isolation capabilities of the site. Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition for postclosure erosion (level 3).

6.3.1.5.7 Plans for site characterization

During construction of the exploratory shaft at Yucca Mountain, walls of the shaft will be geologically mapped and photographed and the stratigraphic characteristics of lithologic units will be recorded. Field investigations will continue to improve the dating of Quaternary deposits and to better establish the local and regional geomorphic history of the Quaternary Period.

6.3.1.6 Dissolution (10 CFR 960.4-2-6)

6.3.1.6.1 Introduction

The qualifying condition for this guideline is as follows:

The site shall be located such that any subsurface rock dissolution will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.

The objective of the dissolution technical guideline is to ensure that dissolution processes will not adversely affect the waste isolation capabilities of the site. The principal concern is that dissolution of the host rock will adversely affect the waste isolation capabilities of the site by creating new pathways for radionuclide migration to the surrounding geohydrologic system. The assessment of compliance with this guideline is to be based on evidence of dissolution in the geologic setting of the site during the Quaternary Period. The question of dissolution is not expected to be of concern at Yucca Mountain because the rock types present are considered to be insoluble.

The dissolution guideline contains one favorable condition, one potentially adverse condition, one disqualifying condition, and one qualifying condition. The evaluations reported in the following sections are summarized in Table 6-32.

6.3.1.6.2 Data relevant to the evaluation

Summary of the available data

The host rock at Yucca Mountain has been extensively studied by drill-hole sampling in and around the exploration block (Heiken and Bevier, 1979; Sykes et al., 1979; Carroll et al., 1981; Spengler et al., 1981; Waters and Carroll, 1981; Bish et al., 1982; Caporuscio et al., 1982; Byers and Warren, 1983; Maldonado and Koether, 1983; Levy, 1984a,b; Scott and Castellanos, 1984; Spengler and Chornack, 1984; Vaniman et al., 1984). The mineralogic characteristics of the host rock are reviewed in a current summary report (Bish et al., 1984). Kerrisk (1983) provides a discussion of reaction-path calculations of volcanic-glass dissolution. The origin of lithophysal cavities in the tuffs has been reviewed (Byers et al., 1976; Lipman et al., 1966). No evidence of Quaternary dissolution fronts or other Quaternary dissolution features has been found.

Assumptions and data uncertainties

There is some evidence of pre-Quaternary hydrothermal systems in older and deeper rocks below the host rock at Yucca Mountain (Bish and Semarge, 1982; Bryant and Vaniman, 1984). The assumption that these systems are no longer active is based on: (1) the intergrowth of younger low-temperature clays over earlier high-temperature clays (Bish and Semarge, 1982), and (2) the lower temperatures (60°C (140°F)) at which these clays now exist in rocks that were hydrothermally altered at high temperatures (180 to 230°C (350 to 450°F)) (Caporuscio et al., 1982). The assumption that solution does not occur in the Topopah Spring Member at Yucca Mountain in low-temperature aqueous systems is supported by the absence of any solution features in drill hole J-13, where the host rock is below the water table (Heiken and Bevier, 1979; Byers and Warren, 1983). Uncertainties in these data are limited to the remote possibility that hydrothermal alteration systems or low-temperature solution zones occur between the present distribution of drill holes and have therefore not been observed. Such sampling uncertainties have not yet been quantified but are expected to be very small.

6.3.1.6.3 Favorable condition

No evidence that the host rock within the site was subject to significant dissolution during the Quaternary Period.

Table 6-32. Summary of analyses for Section 6.3.1.6; dissolution (10 CFR 960.4-2-6)

Condition	Department of Energy (DOE) finding
<p>FAVORABLE CONDITION</p> <div> <p>No evidence that the host rock within the site was subject to significant dissolution during the Quaternary Period.</p> </div> <div> <p>The evidence indicates that this favorable condition is present at Yucca Mountain: no dissolution features have been found or are expected in the potential host rock. Minerals in the host rock are not considered soluble under expected repository conditions.</p> </div>	
<p>POTENTIALLY ADVERSE CONDITIONS</p> <div> <p>Evidence of significant dissolution within the geologic setting--such as breccia pipes, dissolution cavities, significant volumetric reduction of the host rock or surrounding strata, or any structural collapse--such that a hydraulic interconnection leading to a loss of waste isolation could occur.</p> </div> <div> <p>The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: no dissolution mechanism is present that could develop hydraulic interconnections that could lead to a loss of waste isolation.</p> </div>	
<p>QUALIFYING CONDITION</p> <div> <p>The site shall be located such that any subsurface rock dissolution will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.</p> </div> <div> <p>The evidence supports the finding that the site meets the qualifying condition and is likely to continue to meet the qualifying condition (level 4): minerals in the host rock are considered insoluble, and dissolution is not a credible process leading to radionuclide releases.</p> </div>	

Evaluation

The host rock at Yucca Mountain contains no dissolution fronts or other dissolution features. This is true even to the east of the primary repository area, where the host rock is mostly in the saturated zone (Heiken and Bevier, 1979; Byers and Warren, 1983). None of the reports listed under relevant data in this section cite any evidence of dissolution in the host rock. The mineralogy of the host rock is simple (Bish et al., 1984); more than 98 percent consists of feldspar, quartz, cristobalite, and tridymite; the remainder consists of other silicate and oxide minerals. Under the repository conditions expected at Yucca Mountain, none of these minerals dissolve in water to any meaningful degree.

Conclusion

There is no evidence that the host rock at Yucca Mountain was subject to any dissolution during the Quaternary Period. None of the minerals in the host rock is considered soluble under expected repository conditions. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

6.3.1.6.4 Potentially adverse condition

Evidence of dissolution within the geologic setting--such as breccia pipes, dissolution cavities, significant volumetric reduction of the host rock or surrounding strata, or any structural collapse--such that a hydraulic interconnection leading to a loss of waste isolation could occur.

Evaluation

As stated under the favorable condition, the potential host rock at Yucca Mountain has no dissolution features. This is also true for other rocks at the site, as described in the reports listed under relevant data in this section. While there is some evidence of hydrothermal alteration in the older and deeper rocks below the host rocks (Bish and Semarge, 1982; Bryant and Vaniman, 1984) the evidence indicates that these hydrothermal systems are no longer active and did not result in significant dissolution (Bish and Semarge, 1982; Caporuscio et al., 1982). These deeper zones of pre-Quaternary hydrothermal alteration are dense and nonporous because of secondary mineral precipitation (Caporuscio et al., 1982). The lithophysal cavities that are present in the host rock were formed by the entrapment of gases during the crystallization of the hot volcanic material about 13 million years ago (Byers et al., 1976; Lipman et al., 1966); they are not Quaternary dissolution features. Some lithophysal margins exhibit cross-cutting or overprinted textures that were developed as the lithophysae formed and do not represent Quaternary dissolution fronts (Caporuscio et al., 1982).

Conclusion

At the Yucca Mountain site, there is no evidence of significant dissolution that would provide a hydraulic interconnection between the host rock and any immediately surrounding geohydrologic unit. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

6.3.1.6.5 Disqualifying condition

The site shall be disqualified if it is likely that, during the first 10,000 years after closure, active dissolution, as predicted on the basis of the geologic record, would result in a loss of waste isolation.

Evaluation

The host rock of Yucca Mountain consists of the densely welded and devitrified portion of the unsaturated Topopah Spring Member. About 98 percent of the host rock consists of alkali feldspars, quartz, cristobalite, and tridymite. These minerals are not prone to dissolution in any significant quantities. No evidence of Quaternary dissolution fronts or other Quaternary dissolution features has been found, as discussed under the favorable condition.

Conclusion

On the basis of the geologic record, no dissolution is expected during the first 10,000 years after repository closure, or thereafter. Therefore, the evidence supports a finding that the site is not disqualified on the basis of that evidence and is not likely to be disqualified (level 2).

6.3.1.6.6 Evaluation and conclusion for the qualifying condition on the postclosure dissolution guideline

Evaluation

For all practical purposes the volcanic rocks of Yucca Mountain are not subject to dissolution. The guideline on dissolution applies to soluble rocks (such as salt) that can dissolve at much higher rates than the tuffs of Yucca Mountain. In particular, there is no evidence that the host rock at the site was subject to dissolution during the Quaternary Period, nor is there any reason to suspect that dissolution within the site would provide a hydraulic interconnection between the host rock and the immediately surrounding geohydrologic units. The minerals that compose the rock in and around the site are considered to be insoluble, and no significant dissolution is expected to occur even at the elevated temperatures in the underground repository. Consequently, the formation of active dissolution fronts is not credible for the conditions at Yucca Mountain.

Conclusion

The minerals that compose the rock in and around the Yucca Mountain site are considered insoluble, and significant subsurface rock dissolution is not a credible process leading to radionuclide releases greater than those allowable under the requirements specified in 10 CFR 960.4-1 (1984). Therefore, on the basis of the above evaluation, the evidence supports a finding that the site meets the qualifying condition, and is likely to continue to meet the qualifying condition for postclosure dissolution (level 4).

6.3.1.6.7 Plans for site characterization

Extensive sampling of the proposed horizon is planned during sinking of the exploratory shaft and in situ testing. Other in situ tests will determine the amount of host rock dissolution/precipitation that is possible in the high-temperature zones of the underground facility.

6.3.1.7 Tectonics (10 CFR 960.4-2-7)

6.3.1.7.1 Introduction

The qualifying condition for this guideline is as follows:

The site shall be located in a geologic setting where future tectonic processes or events will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.

The objective of the postclosure tectonics guideline is to ensure that tectonic processes do not adversely affect the waste-isolation capabilities of a potential repository at the site. This guideline requires that the tectonic history of a site be carefully examined to determine whether the likelihood for future tectonic activity is acceptably small. The tectonic processes that might adversely affect waste isolation after closure are (1) faulting and ground motion, (2) uplift or subsidence, and (3) volcanic activity.

The prediction of future geologic and tectonic processes and corresponding events is uncertain and difficult. The tectonic history of a site, particularly during the Quaternary Period, must be thoroughly examined, and the results of this examination must be used to forecast future tectonic activity and the possible effects of that activity on the isolation capabilities of the site.

The postclosure tectonics guideline consists of one favorable condition, six potentially adverse conditions, one disqualifying condition, and one qualifying condition. The evaluations reported below are summarized in Table 6-33 for all conditions except the disqualifying condition.

Table 6-33. Summary of analyses for Section 6.3.1.7; postclosure tectonics (10 CFR 960.4-2-7)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITION	
<p>The nature and rates of igneous activity and tectonic processes (such as uplift, subsidence, faulting, or folding), if any, operating within the geologic setting during the Quaternary Period would, if continued into the future, have less than one chance in 10,000 over the first 10,000 years after closure of leading to releases of radionuclides to the accessible environment.</p>	<p>The evidence indicates that this favorable condition is not present at Yucca Mountain: the higher bound on the probability of a basaltic event is estimated at slightly greater than one chance in 10,000 over the next 10,000 years; consequences of other tectonic processes or events are not expected to increase potential for release because low groundwater flux and long travel times are expected to prevent release at the accessible environment for at least 10,000 years following closure.</p>
POTENTIALLY ADVERSE CONDITIONS	
<p>(1) Evidence of active folding, faulting, diapirism, uplift, subsidence, or other tectonic processes or igneous activity within the geologic setting during the Quaternary Period.</p>	<p>The evidence indicates that this potentially adverse condition is present at Yucca Mountain: Quaternary volcanism 230,000 years and older and recurrent Quaternary faulting are found in the vicinity of the site.</p>
<p>(2) Historical earthquakes within the geologic setting of such magnitude and intensity that, if they recurred, could affect waste containment or isolation.</p>	<p>The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: the historical record and geologic evidence indicate no large earthquakes that would be expected to affect containment or isolation if they recurred.</p>
<p>(3) Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or the magnitude of earthquakes within the geologic setting may increase.</p>	<p>The evidence indicates that this potentially adverse condition is present at Yucca Mountain: future increase in frequency or magnitude of earthquakes at or near Yucca Mountain cannot be ruled out on the basis of available information.</p>

Table 6-33. Summary of analyses for Section 6.3.1.7; postclosure tectonics (10 CFR 960.4-2-7) (continued)

Condition	Department of Energy (DOE) finding
(4) More-frequent occurrences of earthquakes of higher magnitude than are representative of the region in which the geologic setting is located.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: the earthquake frequency and magnitude for the geologic setting are the same as or less than the frequency and magnitude of the region.
(5) Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such magnitudes that they could create large-scale surface-water impoundments that could change the regional ground-water flow system.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: landslides, subsidence, and volcanic activity are not expected; even if they occurred, they would not be expected to cause surface-water impoundments or change the regional ground-water flow system.
(6) Potential for tectonic deformations--such as uplift, subsidence, folding, or faulting--that could adversely affect the regional ground-water flow system.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: large-scale structures control the ground-water system, and tectonic deformations of a magnitude or scale to affect the regional flow system are not expected.
<p style="text-align: center;">QUALIFYING CONDITION</p> <p>The site shall be located in a geologic setting where future tectonic processes or events will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.</p>	
<p>Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): potential tectonic events are not likely to cause radionuclide releases greater than allowable; low water flux and travel times greater than 10,000 years in the unsaturated zone are expected to prevent dissolution and transport of radionuclides.</p>	

6.3.1.7.2 Data relevant to the evaluation

Summary of available data

Much of the background data for the tectonic appraisal of the Nevada Test Site area has been developed through many years of surface and sub-surface geologic and geophysical studies related to nuclear-weapons testing. The present investigations of Yucca Mountain and its vicinity have built upon this data base by addressing specific subjects, such as faulting (Swadley et al., 1984; Dudley, 1985), regional tectonics (Carr, 1984), stress measurements (Healy et al., 1984), and volcanism (Crowe et al., 1982, 1983; Link et al., 1982). Data are also available on the special techniques used in the evaluation, such as thermoluminescence dating (Wintle and Huntley, 1982). However, much of the published data bearing upon the tectonic stability of the Yucca Mountain region are in the form of progress or preliminary reports, and much work remains to complete the data base. Data are also available on the surficial geology of the site (Scott and Bonk, 1984; Christiansen and Lipman, 1965; Lipman and McKay, 1965) and on ground-water flux rates and chemical and mechanical retardation in the host rock (Wilson, 1985; Sinnock et al., 1984; Travis et al., 1984).

Seismological data of consistent quality have been obtained for only the last few years (Rogers et al., 1983), but two previous reports (Rogers et al., 1976, 1977) provide preliminary data applicable to Yucca Mountain. The historical record of earthquakes within about 10 kilometers (6 miles) of Yucca Mountain has been summarized (USGS, 1984; Rogers, 1986). Seismic data and evaluations for the western United States are also available (Smith, 1978; VanWormer and Ryall, 1980; Thenhaus, 1983; Thenhaus and Wentworth, 1982) and predictions of regional recurrence intervals are taken from Greensfelder et al. (1980) and Ryall and VanWormer (1980). Information about the damage to be expected in underground structures is also available (Pratt et al., 1978, 1979). The acquisition of geodetic data was begun in 1983, but several years of observations will be required before sufficient data are available for analysis.

Workshops were held to review ground motion and related issues for the Yucca Mountain site. A report from these workshops is available (SAIC, 1986).

Assumptions and data uncertainties

The principal assumption is that the geologic history, particularly the history of the Quaternary period (approximately the last 1.8 million years), can be used as the basis for predicting the course of future events. Uncertainties in determining the Quaternary history of the geologic setting of the site arise from the scarcity of precise data on Quaternary deposits and from the difficulty in determining the current tectonic state of this setting with respect to cycles of activity.

6.3.1.7.3 Favorable condition

The nature and rates of igneous activity and tectonic processes (such as uplift, subsidence, faulting, or folding), if any, operating within the geologic setting during the Quaternary Period would, if continued into the future, have less than one chance in 10,000 over the first 10,000 years after closure of leading to releases of radionuclides to the accessible environment.

The conditional probability that a basaltic magmatic intrusion will occur in the future and will intersect a repository at Yucca Mountain during the 10,000 year isolation period is bounded by the range of 4.7×10^{-4} to 3.3×10^{-6} (based on calculations by Crowe et al., 1982). The upper bound probability was calculated on the basis of extremely conservative assumptions, and for this reason, preliminary approximations of mean probability values were calculated from the data presented in Tables IV and V in Crowe et al. (1982), assuming a Gaussian data distribution. The mean probability value calculated on the basis of magma production rate is 7.7×10^{-5} with a standard deviation of 0.11×10^{-5} (Table IV); the mean probability value based on volcanic cone counts is 2.0×10^{-4} with a standard deviation of 1.28×10^{-4} (Table V); and the combined mean using all calculated probability values is 1.3×10^{-4} with a standard deviation 1.33×10^{-4} . Additional investigations are needed to more accurately evaluate the probability of volcanic activity in the Yucca Mountain region.

Probability calculations are not yet available for other tectonic processes. Various investigations are in progress to evaluate more fully the tectonic stability of Yucca Mountain and the surrounding area; they include long-term seismic monitoring, geodetic measurements, and studies of Quaternary faulting and erosion rates. Preliminary studies suggest that the average rate of faulting in the region of Yucca Mountain during the last 2 million years has been less than 0.01 meter (0.03 foot) per 1,000 years (Carr, 1984). Investigations to date covering a 1,100 square-kilometer (425 square-mile) area around the site have found 32 faults that offset or fracture Quaternary deposits. Quaternary faults have been divided into 3 broad age groups as follows: 5 faults last moved between about 270,000 and 40,000 years ago; 4 faults last moved about 1 million years ago; and 23 faults last moved probably between 2 million years and 1.2 million years ago (Swadley et al., 1984). However, work is ongoing to more accurately determine the detailed history of Quaternary fault movement for faults at and near the site. Without this more detailed data, there is uncertainty regarding the expected rate and amount of faulting over the next 10,000 years. Recurrence intervals for earthquakes in the region have been estimated by a number of approaches and are reviewed in the evaluation of the disqualifying condition, Section 6.3.1.7.5. The reported recurrence interval is on the order of 25,000 years for earthquakes of magnitude $M \geq 7$.

Information about the potential effects of earthquakes on underground structures is reviewed in Section 6.3.3.4.5 and indicates that damage in mines is generally less than that at the surface. Damage is not likely to occur unless the mine is very close to the earthquake epicenter. The primary cause of earthquake-induced failure in underground excavations is apparently movement along preexisting faults or collapse at the portal of the tunnel or shaft.

After repository closure, the effect of earthquakes and fault movement on release of radionuclides to the accessible environment is expected to be minimal because very little water is expected to be available to dissolve and transport radionuclides (Wilson, 1985). Using the travel-time estimates from Section 6.3.1.1.5, even if a waste disposal container were breached by fault movement that occurred immediately after closure, no water containing radionuclides could reach the accessible environment for at least 10,000 years and as shown in Section 6.3.1.2.3, chemical and mechanical retardation processes are expected to extend the travel times for radionuclides by at least a factor of 100 (Sinnock et al., 1984; Travis et al., 1984). It is unlikely that seismic activity would cause increases in the flux through the unsaturated zone because flux is controlled by the percentage of precipitation that infiltrates to become percolation. New fractures are unlikely and, if formed, are also unlikely to significantly alter flow conditions because the area is already highly fractured. In addition, care will be taken during waste emplacement to carefully consider the consequences of emplacement in or near recognizable fault zones. It is therefore considered extremely unlikely that faulting could lead to radionuclide releases to the accessible environment over the first 10,000 years after closure.

Conclusion

During the Quaternary Period, various tectonic processes occurred within the geologic setting of Yucca Mountain. The probability of a magmatic intrusion that intersects the repository is on the order of 1 chance in 10,000 over the next 10,000 years. Numerical probabilities are not available for other tectonic processes and events. Low water flux and long travel times should ensure that if radionuclides were released as the result of tectonic activity, they could not reach the accessible environment for at least 10,000 years. Nevertheless, a conservative position is appropriate because of the absence of probability values for most tectonic processes and events and because the upper bound on volcanic event probabilities is larger than the value specified by this condition. Therefore, the evidence indicates that this favorable condition is not present at Yucca Mountain.

6.3.1.7.4 Potentially adverse conditions

- (1) Evidence of active folding, faulting, diapirism, uplift, subsidence, or other tectonic processes or igneous activity within the geologic setting during the Quaternary Period.

Evaluation

There is evidence of gentle regional tilting to the southeast of about 4 meters per kilometer (20 feet per mile) during the last few million years (Carr, 1984). At the time of publication of Swadley et al. (1984) there was no unequivocal evidence that surface fault displacement had occurred within a 1,100 square-kilometer (425 square-mile) area around the Yucca Mountain site in the past 40,000 years. However, preliminary dates of a displaced silt horizon obtained by thermoluminescence methods may indicate surface fault displacement on the order of 1 to 10 centimeters in the eastern part of

Crater Flat more recently than about 6,000 years ago (Dudley, 1985). Thermoluminescence is a dating technique that has been used in archaeology, but has not yet been shown to provide reliable dates in geologic applications (Wintle and Huntley, 1982). Ongoing studies to improve the dating of fault displacement in the area will determine the reliability of these preliminary data. A new fault map of the Yucca Mountain site has been prepared by Scott and Bonk (1984) and is shown in Figure 6-20. Continued surface mapping and determination of most recent displacements on faults that are located at and near Yucca Mountain will be an important part of seismic hazard assessment during site characterization. For a more thorough discussion of plans for seismic and tectonic evaluations, see Section 6.3.3.4.5.

Detection of earthquakes in the magnitude (M) ranges $M = 4$ to 5 , $M = 5$ to 6 , $M = 6$ to 7 , and $M = 7$ to 8 is complete for the most recent 40, 50, 60, and 130 years, respectively, according to USGS (1984). The earthquake record prior to 1978 shows that within about 10 kilometers (6 miles) of Yucca Mountain, 7 earthquakes occurred; 2 had magnitudes of $M = 3.6$ and $M = 3.4$; magnitudes were not reported for the remaining 5 earthquakes. They were apparently very small or had magnitudes that could not be determined due to instrument problems. Prior to 1978, standard errors of most locations were ± 7 kilometers (± 4.2 miles) or more (USGS, 1984). A new seismic network has recorded 3 microearthquakes in the same area between August 1978 and the end of 1983; the largest magnitudes (M_L , Richter scale) were approximately $M = 2$ (Rogers, 1986).

Within the 1,100 square-kilometer (425 square-mile) area around the Yucca Mountain site, 32 faults have been identified as having some evidence of at least a small amount of movement during the Quaternary Period that probably occurred before about 40,000 years ago. Five faults are thought to have last moved between about 270,000 and 40,000 years ago. The remainder of the faults are thought to have last moved between 1 and 2 million years ago (Swadley et al., 1984).

Basaltic eruptions of Late Cenozoic age in the Yucca Mountain area are listed in Table 6-34. Basaltic eruptions occurred periodically in the Crater Flat area west and south of Yucca Mountain during the Quaternary Period (Crowe et al., 1982).

Conclusion

There is evidence of faulting and basaltic volcanism during the Quaternary Period within the geologic setting of Yucca Mountain. There is regional tilting which results in very slow uplift and subsidence. Therefore, the evidence indicates that this potentially adverse condition is present at Yucca Mountain.

(2) Historical earthquakes within the geologic setting of such magnitude and intensity that, if they recurred, could affect waste containment or isolation.

Figure 6-20. Geologic map of Yucca Mountain; primary repository area indicated with dashed line. Modified from Scott and Bonk (1984).

Table 6-34. Potassium-argon ages of late Cenozoic basalts in Yucca Mountain area^a

	Age (million years)	Mean Age (million years)
Lathrop Wells	0.29 $\pm$ 0.2	
Volcanic Center	0.23 $\pm$ 0.02	0.27
	0.30 $\pm$ 0.10	
Western Rift,	1.14 $\pm$ 0.3	
Crater Flat	1.07 $\pm$ 0.04	
	1.09 $\pm$ 0.3	
	1.07 $\pm$ 0.4	1.16
	1.11 $\pm$ 0.3	
	1.50 $\pm$ 0.1	
Basalt of Sleeping	0.29 $\pm$ 0.11	
Butte	0.32 $\pm$ 0.15	0.28
	0.24 $\pm$ 0.22	
Basalt of Buck-	2.82 $\pm$ 0.04	2.81
board Mesa	2.79 $\pm$ 0.10	

^aData from Crowe et al. (1982).

Evaluation

The peak historical ground acceleration at a location 20 kilometers (12 miles) east of Yucca Mountain is estimated to have been less than 0.1g (Rogers et al., 1977). Pre-1978 historical seismic activity within 10 kilometers (6 miles) of Yucca Mountain shows only 2 earthquakes with Richter magnitudes greater than $M = 3$. Detection of earthquakes in the magnitude ranges $M = 4$ to 5, $M = 5$ to 6, $M = 6$ to 7, and $M = 7$ to 8 is complete for the most recent 40, 50, 60, and 130 years, respectively, according to USGS (1984). Although surface faulting has been observed at Pahute Mesa and Yucca Flat in response to nuclear explosions (SAIC, 1986), the closest historical surface faulting accompanying natural earthquakes occurred in 1872 with a magnitude of $M = 8+$ in Owens Valley, California about 150 kilometers (90 miles) west of Yucca Mountain (Rogers et al., 1977, 1976). This great earthquake occurred on the western margin of the Basin and Range Province, along the Sierra Nevada-Great Basin Boundary Zone (VanWormer and Ryall, 1980), which is a fundamental discontinuity between two contrasting structural domains. The Yucca Mountain area, in contrast, lies on the edge of the East-West Seismic Belt between an area of moderate seismicity on the north, and an area of lower seismicity to the south (see Section 6.3.1.7.5). Two earthquakes with magnitudes of $M = 6$ have occurred within about 200 kilometers (125 miles) of Yucca Mountain; one occurred in 1908, 110 kilometers

(68 miles) southwest of Yucca Mountain, and one occurred in 1966, about 210 kilometers (130 miles) to the northeast. If the historical earthquakes recurred, they would not be large enough or close enough to Yucca Mountain to have any demonstrable effect on waste containment or isolation (see the qualifying condition evaluation in Section 6.3.1.7.6).

Conclusion

The historical record does not show any earthquakes within the geologic setting of Yucca Mountain that, if they recurred, could adversely affect waste containment or isolation. Furthermore, the historical record discloses no evidence of damaging ground motion or faulting at or near Yucca Mountain. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(3) Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or the magnitude of earthquakes within the geologic setting may increase.

The potential repository site at Yucca Mountain and a large area to the west and south have had a relatively low level of seismicity throughout the historical record (Rogers et al., 1983). The historic earthquake record prior to 1978 shows that within about 10 kilometers (6 miles) of the site, there were 7 earthquakes; 2 had magnitudes of $M = 3.6$ and $M = 3.4$; magnitudes were not reported for the remaining 5 earthquakes. They were apparently very small or had magnitudes that could not be estimated due to instrument problems. A new seismic network has recorded 3 minor earthquakes in the same area between August 1978 and the end of 1983; the largest magnitudes (M_L , Richter scale) were approximately $M = 2$ (USGS, 1984).

Geologic evidence available to date indicates that 32 faults within a 1,100 square-kilometer (425 square-mile) area around the site offset or fracture Quaternary deposits. Five faults are thought to have last moved between about 270,000 and 40,000 years ago. Four faults last moved about 1 million years ago; and 23 faults are thought to have last moved between 2 and 1.2 million years ago (Swadley et al., 1984).

One of the results of ongoing studies is an indication that fault orientation may be more important than evidence of recent movement in determining the potential for renewed activity (Rogers et al., 1983). Microseismic data for Yucca Mountain and a large area to the west and south indicate that faults with strikes from approximately north to northeast appear to be more active than faults of other orientations (Rogers et al., 1983). At present, a preliminary conclusion could be made that the north-trending faults at Yucca Mountain should be considered potentially active even though the absence of fault scarps and the near absence of seismic activity suggest that they are not active (Rogers et al., 1983). It should be noted that the age of most recent surface displacement on a fault does not necessarily correlate with the degree of present seismicity on the fault. This lack of correlation is indicated by the abundant seismicity on fault zones with no record of Quaternary displacement and by the absence of seismicity in some areas of Quaternary faulting (Rogers et al., 1983; USGS, 1984).

From the historical seismicity of the southern Great Basin (two earthquakes of $M = 6$), and length of active faults, a maximum magnitude of $M = 7$ to 8 is inferred for earthquakes in the Yucca Mountain region (USGS, 1984). The wide range of focal depths (0 to 10 kilometers (0 to 6 miles)) indicates that some faults in the southern Great Basin extend to considerable depth and thus have large surface areas that would make them capable of producing large earthquakes (USGS, 1984).

The nature of seismic cycles and the relation between the potential for seismicity and the age of most recent movement on faults in the Basin and Range Province are not resolved (see Thenhaus (1983) for a summary of views). Until there is a better understanding of why some areas are stable and other areas are unstable in the same region, it is not possible to rule out future seismic activity on faults at Yucca Mountain (Rogers et al., 1983). This position is taken partly because (1) interpretation of stress measurements at Yucca Mountain could indicate that certain faults may be potentially active (Healy et al., 1984) and (2) faults similar in orientation and style to those at Yucca Mountain exist on Pahute Mesa, where large nuclear tests have resulted in displacement on faults for a distance approaching 10 kilometers (6 miles) in length. Although movement on the faults at Pahute Mesa was induced by nuclear explosions, the extent of faulting, the size of fault displacements, and the magnitude and depths of the accompanying aftershocks indicate that these faults may have been tectonically stressed near the failure point and that slip was triggered by stress changes produced by the explosions (USGS, 1984). It should also be noted that in situ stress measurements alone do not allow quantitative statements about earthquake probability and magnitude (SAIC, 1985b).

Available information is insufficient to determine whether future seismic activity is likely to be more frequent, or of higher magnitude than historic seismicity. In order to provide a consistent interpretation of this potentially adverse condition, the maximum earthquake magnitude in the historical record and the record of Quaternary faulting within the geologic setting are assumed to be the strongest indicators of future earthquake potential for the postclosure time frame. Difficulty in interpreting the Quaternary faulting record leads to the conclusion that the historical record may not reveal the largest earthquake that could occur at Yucca Mountain. Given this interpretation, a conservative position is that the geologic setting of the Yucca Mountain site may experience earthquakes of higher magnitude or frequency than have been historically observed.

Conclusion

The record of Quaternary faulting and the nature of earthquake occurrence in the geologic setting of Yucca Mountain is not understood well enough to permit reliable correlations of earthquakes with tectonic processes and features. In the absence of such correlations, the conservative assumption is that earthquakes larger than those that have historically occurred in the geologic setting of Yucca Mountain may occur in the future. Therefore, the evidence indicates that this potentially adverse condition is present at Yucca Mountain.

(4) More-frequent occurrences of earthquakes or earthquakes of higher magnitude than are representative of the region in which the geologic setting is located.

Evaluation

The Yucca Mountain site is located within the Basin and Range Province and is adjacent to a zone of seismicity considered part of the East-West Seismic Belt in southern Nevada (see Figure 6-21). This belt connects the north-trending Nevada Seismic Belt, about 160 kilometers (100 miles) west of the site, with the north-trending Intermountain Seismic Belt more than 250 kilometers (156 miles) east of the site. Each of these zones of seismicity spans large areas that are heterogeneous in their geologic and seismologic properties (Thenhaus and Wentworth, 1982). There are two earthquakes in the historical record within about 200 kilometers of Yucca Mountain with magnitudes of $M = 6$; one at Death Valley in 1908, 110 kilometers (68 miles) southwest of the site and the second in 1966, about 210 kilometers (130 miles) to the northeast.

The evaluation of the previous potentially adverse condition reviews the historical record of seismicity for the Yucca Mountain site. The evaluation indicates that it is not possible to rule out future seismic activity on faults at and near Yucca Mountain. However, there is no reason to believe that this seismic activity is likely to be more frequent or of higher magnitude than is typical for the southern Basin and Range Province.

Conclusion

The frequency and magnitude of earthquakes at and near Yucca Mountain during the several years of close monitoring is the same as or less than that for the southern Basin and Range Province. There is no reason to expect that future seismicity at the site is likely to be more frequent or of higher magnitude than is representative of the region in which the geologic setting is located. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(5) Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such magnitudes that they could create large-scale surface-water impoundments that could change the regional ground-water flow system.

Evaluation

There is no evidence that subsidence related to dissolution of rocks has occurred, nor are there soluble rocks at the surface or within at least 1,200 meters (3,940 feet) of the surface of Yucca Mountain. Geologic and geomorphic evidence of landslides (Christiansen and Lipman, 1965; Lipman and McKay, 1965; Scott and Bonk, 1984) is limited to relatively small rock slumps along steep erosional slopes of Yucca Mountain. The largest of these slumps is on the northeast side of Yucca Mountain along Yucca Wash, where a set of blocks 500 meters (1,640 feet) wide is slumping into the wash along a complex of 14 minor normal faults that strike parallel to the wash. There is no geomorphic evidence of rapid movement of these blocks, and lateral movement

Figure 6-21. Historical seismicity in the western United States showing the Nevada Seismic Belt, the Intermountain Seismic Belt, and the Southern Nevada East-West Seismic Belt. It should be noted that some of the seismicity in the western end of the East-West Seismic Belt represents underground explosions at the Nevada Test Site. For California, the minimum-magnitude earthquakes plotted were Richter $M \sim 1$; for the rest of the western United States they were Richter $M \sim 3$. Modified from Smith (1978).

seems to be limited to that observed along normal fault planes that dip 60 to 80°. There is no geomorphic evidence that past slumping of blocks has dammed major drainageways. Furthermore, the slopes do not have a thick cover of soil or colluvial material that could slide down and create dams.

If basaltic eruptions were to occur at or near Yucca Mountain, they might temporarily dam washes. The most recent nearby volcanism occurred at several small basaltic cones that are about 270 thousand to 3.7 million years old and located 8 to 15 kilometers (5 to 9 miles) west and southwest of the site. See Table 6-34 for ages of basalts in the area.

Sites of active basaltic and subordinate silicic volcanism progressively shifted toward the margins of the southwestern Great Basin beginning about 10 million years ago (Crowe et al., 1983), and the likelihood of future eruptions at Yucca Mountain during the time important to waste isolation is small as indicated by the evaluation of favorable condition 1.

Under expected climatic conditions over the next 10,000 years (see Section 6.3.1.4) it is unlikely that sufficient surface runoff could be impounded by any of the above tectonic processes, were they to occur, to change the regional ground-water flow systems.

Conclusion

The creation of large-scale surface-water impoundments by natural phenomena such as landslides, subsidence, or volcanic activity is not likely in the Yucca Mountain area. No effect on the regional ground-water flow system is expected from landslides, subsidence, or volcanic activity. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(6) Potential for tectonic deformations--such as uplift, subsidence, folding, or faulting--that could adversely affect the regional ground-water flow system.

Evaluation

Calculations of the amount and the rate of subsidence, uplift, or faulting in the southern Great Basin show that over the last few million years Yucca Mountain and adjacent areas have been relatively stable, particularly in comparison with tectonically active areas, such as Death Valley and Owens Valley (Table 6-35) (Carr, 1984). Folding has not been active in the vicinity of Yucca Mountain for millions of years, although tilting and folding have occurred in the Death Valley region during Pliocene and Quaternary time. Work in progress suggests that gentle warping of Quaternary deposits might have occurred as close to Yucca Mountain as the west side of Crater Flat. An assessment of tectonic warping will be a part of the site characterization process. A level line was run through the Yucca Mountain area in the winter of 1982-1983, and the following winter it was rerun without evidence of change. During November 1985, the line will be upgraded and extended through Mercury, Nevada, to create a level loop originating and terminating at a first-order National Geodetic Survey line.

Table 6-35. Approximate rates of relative vertical tectonic adjustment or burial at selected locations in the southwestern Great Basin during the late Neogene and Quaternary^a

Location	Rate (meters per 1,000 years or millimeters per year)	Comment
S. Amargosa Desert Valley	<0.01	Based on a 3-million-year old ash bed in lake deposits about 5 meters below the surface.
Crater Flat, central	<0.01	Basalt dated by potassium-argon method at 1.2 million years is at the present surface and has not been deformed or subsided into the basin.
Crater Flat, eastern	<0.01	Based on an offset in alluvium (allowing for 0.6 meter of erosion) of 3.0 meters in 1.1 million years.
Crater Flat, southeastern	<0.02	Offset of alluvium in a minimum time of 40,000 years. Actual time was probably closer to 260,000 years.
Crater Flat, USW VH-2 drill hole	0.03	Burial of basalt about 11 million years old.
Yucca Mountain	0.03	Based on maximum of 460 meters of offset of Tiva Canyon Member in last 12.8 million years. For the Quaternary, a very conservative estimate is <0.01 meters per 1,000 years, based on maximum credible amount of displacement (10 meters) in Quaternary time.
N. W. Frenchman Flat	0.06 ^b	Burial of 3-million-year old ash bed at depth of 195 meters; not in most active part of the Frenchman Flat Basin.
S. Yucca Flat	0.16 ^b	Based on amount of displacement of an 8.1-million-year old basalt in drill holes.
Searles Valley	0.22 ^b	Burial of 3-million-year old ash bed in core at depth of 691 meters.

Table 6-35. Approximate rates of relative vertical tectonic adjustment or burial at selected locations in the southwestern Great Basin during the late Neogene and Quaternary^a (continued)

Location	Rate (meters per 1,000 years or millimeters per year)	Comment
Death Valley, foot of Black Mountains	0.3	Based on estimated displacement of Artist's Drive Formation of 1,525 meters in 5 million years.
Sierra Nevada- Owens Valley- White-Inyo Mountains	0.4	Average of 9 estimates (range 0.2-1.0 meters per 1,000 years).
Coso Range- Rose Valley	1.8	Offset of 2.5 million-year-old lava flow.

^aData from Carr (1984).

^bMaximum rate.

The available data on several specific faults in the Yucca Mountain area seem to show generally decreasing rates and amounts of offset through about the last 10 million years (Carr, 1984). The data for older faulting are obtained at locations where the offset of several volcanic units of known ages can be determined. Control for dating events of the last 8 million years depends mainly on understanding and dating alluvial-stratigraphic units that have limited vertical exposures. The absolute ages of some of these units are not well known at present. Approximately 180 scarps or lineaments that are presumed to be fault related have been identified within 100 kilometers (62 miles) of Yucca Mountain (Carr, 1984). About one-fourth of these are linear or curvilinear mountain fronts; the remaining 135 are actual fault scarps or lineaments in the alluvium. Most of the alluvial scarps are low and subdued by erosion. Ages of movement on faults that offset Quaternary deposits are reviewed in the above evaluation of potentially adverse condition 3.

The rates of uplift, subsidence, or faulting in the past have been very low; it is postulated that similar rates will prevail in the future. If the rates of uplift, subsidence, or faulting in a portion of the ground-water system were significantly changed relative to those of other portions of the system, the ground-water flow path between the repository and the accessible environment could be affected. Ground-water flow could be either retarded or accelerated. However, the scale of the effects on ground-water flow are expected to be small because the present ground-water system is controlled by

large regional structures that probably could not be altered significantly by tectonic events during the time period important to waste isolation.

Conclusion

The Yucca Mountain site has a very small potential for tectonic deformations like uplift, subsidence, folding, or faulting of a magnitude or scale that would affect regional ground-water flow. The regional ground-water system is controlled by geologic structures of such complexity and scale that it could not be significantly modified over short time periods by any expected tectonic event. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

6.3.1.7.5 Disqualifying condition

A site shall be disqualified if, based on the geologic record during the Quaternary Period, the nature and rates of fault movement or other ground motion are expected to be such that a loss of waste isolation is likely to occur.

Evaluation

The potential repository site at Yucca Mountain and a large area to the west and south have had a relatively low level of seismicity throughout the historical record (Rogers et al., 1983). The historic earthquake record prior to 1978 shows that within about 10 kilometers (6 miles) of the site, there were 7 earthquakes; 2 had magnitudes of $M = 3.6$ and $M = 3.4$; magnitudes for the remaining 5 were not reported. They were apparently very small or had magnitudes that could not be estimated due to instrument problems. A new seismic network has recorded 3 minor earthquakes in the same area between August 1978 and the end of 1983; the largest magnitudes (M_L , Richter scale) were approximately $M = 2$ (Rogers, 1986). Within about 200 kilometers (124 miles) of Yucca Mountain, there have been two historical earthquakes with Richter magnitudes of $M = 6$. One earthquake occurred in 1908 at Death Valley about 110 kilometers (68 miles) southwest of Yucca Mountain, and the other occurred in 1966, about 210 kilometers (130 miles) northeast of the site. The Owens Valley, California, earthquake of 1872, which is estimated to have had a magnitude of $M = 8+$ on the Richter scale, represents the closest historical surface faulting. It was located about 150 kilometers (90 miles) west of the site in a different seismic zone (see Section 6.3.1.7.4, potentially adverse condition 2).

Geologic evidence available to date indicates that 32 faults within a 1,100 square-kilometer (425 square-mile) area around the site offset or fracture Quaternary deposits. Five faults are thought to have last moved between about 270,000 and 40,000 years ago. The remainder of the faults are thought to have last moved between 1 and 2 million years ago (Swadley et al., 1984). At the time of publication of Swadley et al. (1984) there was no unequivocal evidence that surface fault displacement had occurred within a 1,100 square-kilometer (425 square-mile) area around the Yucca Mountain site in the past 40,000 years. However, preliminary dates of a displaced silt horizon

obtained by thermoluminescence methods may indicate surface fault displacement on the order of 1 to 10 centimeters in the eastern part of Crater Flat more recently than about 6,000 years ago (Dudley, 1985). Thermoluminescence is a dating technique that has been used in archaeology, but has not yet been shown to provide reliable dates in geologic applications (Wintle and Huntley, 1982). Ongoing studies to improve the dating of fault displacement in the area will determine the reliability of these preliminary data.

Deformation rates at Yucca Mountain during the last approximately 10 million years have been about 4 times less than those in adjacent parts of the Basin and Range Province. Preliminary estimates suggest that a rate of 0.01 meter (0.03 foot) per 1,000 years is a realistic maximum for fault displacement in the Quaternary Period at Yucca Mountain (Carr, 1984).

A number of different approaches have been used to estimate recurrence intervals for earthquakes in the region. Rerupture times (recurrence intervals) estimated for various portions of the Basin and Range Province are assembled from the literature in Table 6-36. The estimates range from 25,000 years for $M \geq 7$, 2,500 years for $M \geq 6$, and 250 years for $M \geq 5$. Recurrence intervals shown in Table 6-36 demonstrate the variability in estimates, resulting from possible real differences for differing regions. The table shows that recurrence intervals for $M \geq 7$ earthquakes for the region south and east of Yucca Mountain are longer than those for the Nevada Test Site (NTS) region by about a factor of 7. At this time, recurrence estimates can only provide insight regarding possible recurrence intervals for faults near Yucca Mountain. Until detailed fault studies are fully completed, there is large uncertainty regarding the appropriate recurrence intervals for these faults. However, the available data (Swadley et al., 1984; Dudley, 1985; and USGS, 1984), furnish no evidence to suggest that the recurrence interval would be shorter than on the order of 25,000 years for major ($M \geq 7$) earthquakes. It should also be noted that there is no information currently available on the seismogenic potential of faults at or near Yucca Mountain, so that the occurrence of a magnitude 7 earthquake in the area can neither be anticipated nor can it be ruled out.

As noted above, the NTS region occupies an intermediate position between a large area of higher estimated seismicity to the north and an area of lower seismicity in the Las Vegas region to the south (see Figure 6-22). Except for a cluster of seismicity due to the water load of Lake Mead, Figure 6-22 shows a fan-shaped region extending southeast from the repository site that is virtually free of earthquakes of $M = 4$ or larger. USGS (1984) calls attention to the near absence of seismicity at approximately the $M > 4$ level in some parts of a 100-kilometer (60-mile) radius surrounding the site.

Rogers et al. (1983) and USGS (1984) conclude that the seismic evidence suggests that faults of north to northeast trend are most susceptible to slip in the current stress field, citing evidence from stress measurements at Yucca Mountain (Healy et al., 1984) and from faults of similar orientations at Pahute Mesa, where fault movements have been induced by nuclear explosions. For purposes of a preliminary evaluation, the seismic hazard for Yucca Mountain was estimated under the assumption that Yucca Mountain faults were not active. The most likely peak deterministic ground acceleration at Yucca Mountain was estimated to be 0.4g. This acceleration would result from a full-length fault rupture (length 17 kilometers (10 miles), magnitude 6.8)

Table 6-36. Rerupture times for faults in the southern Basin and Range Province

Reference	Area	Rerupture time for $M \geq 7.0$ unless otherwise noted (years)	Comments
Ryall and VanWormer (1980)	Western Great Basin ^a	7,000-10,000 ^b	From instrumental data for 1932-1969 and 1970-1974
Greensfelder et al. (1980)	East-West Seismic Belt, including Nevada Test Site ^c	25,000	Logarithmic mean of two data sets
		2,500 ^d	For earthquakes with $M \geq 6$
		250 ^d	For earthquakes with $M \geq 5$
	Las Vegas Region ^e	190,000	Logarithmic mean of two sets

^aEntire 225,000-square-kilometer region containing Holocene scarps.

^bValues were calculated on the assumption that a typical rupture zone has an area of 1,000 square kilometers, and that such rupture zones are contained within the subject region.

^cBasin and Range Seismotectonic Subprovince 4 of Greensfelder et al. (1980), a 34,000-square-kilometer area containing the Nevada Test Site. (Log $N = 2.60 - 1.0 M$, where N = number of earthquakes of magnitude greater than or equal to M .)

^dRecurrence interval estimates based on data in Greensfelder et al. (1980).

^eBasin and Range Seismotectonic Subprovince 5 of Greensfelder et al. (1980), a 73,000-square-kilometer area of very low seismicity north of 34°N. (Log $N = 1.72 - 1.0 M$, where N = number of earthquakes of magnitude greater than or equal to M .)

on the Bare Mountain Fault, which is 14 kilometers (9 miles) west of the site. The probabilistic results discussed by Rogers et al. (1977) and USGS (1984) demonstrate that uncertainties exist in the evaluation of seismic hazard. Different assumptions regarding the appropriate recurrence model, attenuation relationships, and the identification of specific faults as seismic sources can result in widely different estimates of acceleration for a given probability. At this time, it is premature to place much confidence

Figure 6-22. Historic earthquakes of Mercalli intensity $\geq$ V or magnitude $\geq$ 4.0 within 500 kilometers (311 miles) of the Yucca Mountain site through 1974. Those circles that appear solid indicate multiple events. Modified from USGS (1984).

in these estimates, other than to use them to provide insight, until a more complete assessment can be made of the various input parameters into a probabilistic seismic hazard analysis. During site characterization, the seismogenic potential of faults at and near Yucca Mountain will be evaluated to determine the most probable earthquake and faulting scenarios that will need to be considered for evaluation of postclosure repository performance. Further discussion of the approach to be taken for these investigations is presented in Section 6.3.3.4.5.

The ground motion or faulting that is possible at the Yucca Mountain site is likely to have little effect on waste isolation. It is known that earthquake damage to underground facilities is generally much smaller than surface damage (Pratt et al., 1978, 1979). On the basis of detailed surface mapping, faults that cut the potential repository host rock are expected to have easily recognizable displacement if they are large enough to be of concern. Care will be taken during repository development to avoid recognizable faults that appear to have any possibility of renewed activity. Formation of new faults, although not likely, could affect the durability of the containers during the containment period, with the most serious consequence being container rupture. However, in order for radionuclides to be dissolved from the waste and transported from the repository a sufficient quantity of water must be available. The expected very low flux (less than 0.5 millimeter (0.02 inch) per year) at Yucca Mountain (Wilson, 1985) has been shown to be insufficient to transport radionuclides in quantities that could exceed release limits to the accessible environment (Section 6.4.2). Furthermore, calculations by Sinnock et al. (1984) show that the U.S. Environmental Protection Agency (EPA) limits on cumulative curies released to the accessible environment are not violated for waste package containment times as short as 300 years and fluxes that are 40 times the upper bound of 0.5 millimeter (0.02 inch) per year. Flux limitations and long travel times of more than 10,000 years (see Section 6.3.1.1.5), provide confidence that an earthquake- or fault-induced disruption of the repository would be extremely unlikely to cause radionuclide releases to the accessible environment in excess of those allowable under 40 CFR Part 191 (1985).

Conclusion

The geologic record of faulting during the Quaternary Period suggests that the Yucca Mountain site could experience seismicity and faulting in the future. There is, however, no clear evidence that a major earthquake is likely to occur at or near Yucca Mountain. In addition, the consequence of fault movement on waste isolation in this geologic setting is expected to be minimal. The very low water flux that is available for radionuclide transport ensures that EPA release limits are not likely to be exceeded. Confidence in this prediction is enhanced by conservative calculations showing that ground-water travel times exceed 10,000 years. Therefore, the evidence does not support a finding that the Yucca Mountain site is disqualified (level 1).

6.3.1.7.6 Evaluation and conclusion for the qualifying condition on the postclosure tectonics guideline

The available data and interpretations indicate that silicic volcanism ceased at least 8 million years ago in the southern Great Basin. Basaltic volcanic activity has continued during the last 6 to 8 million years, but in episodes that are separated by millions of years to hundreds of thousands of years (Crowe et al., 1982). The most recent episode of basaltic activity near Yucca Mountain occurred approximately 270,000 years ago. The rates of vertical tectonic adjustments during the last 5 million years, as evidenced by displaced rock units of Pliocene and Quaternary age, have been much lower than those of older episodes (Carr, 1984). As displayed in Table 6-36, recurrence intervals for major earthquakes ($M \geq 7$) in the region have been estimated to be on the order of 25,000 years. Recurrence intervals for $M \geq 6$ earthquakes are reported to be on the order of 2,500 years, and $M \geq 5$ earthquakes have recurrence intervals on the order of 250 years.

Future tectonic events, including volcanism and faulting, are unlikely to lead to loss of waste containment or isolation. The probability that basaltic volcanism will disrupt the Yucca Mountain site over a 10,000-year period is estimated to be about 1 chance in 10,000 (based on data from Crowe et al., 1982). The consequences of this basaltic event were assessed by Link et al. (1982). They estimated the expected radionuclide release over a 10,000 year period, assuming that volcanism occurs between 100 and 10,000 years, to be 1.8 curies or 0.038 curies per 1,000 metric tons of heavy metal (MTHM) for a spent fuel repository. Because the probability of this event is estimated to be less than 0.1 over the 10,000-year period, the U.S. Environmental Protection Agency (EPA) release limits should be multiplied by ten according to 40 CFR 191, Subpart B (1985). The isotopes with the largest expected releases under this scenario, relative to their respective EPA release limits, are plutonium-239 and -240. Both are limited by the EPA to cumulative releases over 10,000 years of 100 curies per 1,000 MTHM, or 1,000 curies per 1,000 MTHM for unlikely events. Expected release under the volcanism scenario for each of these isotopes is 23 curies per 1,000 MTHM. All other isotopes are released in quantities that are much smaller relative to the EPA limits.

It is also unlikely that faulting and strong ground motion could cause loss of containment or isolation. Fault displacement could rupture waste disposal containers intercepted by the fault; however, care will be taken during repository development to avoid recognizable faults that appear to have any possibility of renewed activity. Discussions in the previous section indicate that earthquakes associated with large displacements are likely to occur on prominent fault zones that have already been recognized; an avoidance strategy is therefore plausible during container emplacement. In addition, the unsaturated conditions at Yucca Mountain limit the water available to dissolve and transport radionuclides so much that the potential for loss of isolation is very small. Another concern is the ground motion resulting from a nearby earthquake. This motion is unlikely to be severe enough at depth to cause container rupture, as indicated in the discussion in the preclosure disqualifying condition (Section 6.3.3.4.5). Strength requirements that will be imposed on the containers during surface handling will require that containers be able to withstand impact velocities during drop tests that are much more severe than are likely to be experienced after

emplacement in the repository. Furthermore, studies by Sinnock et al. (1984) have shown that EPA limits on cumulative curies released to the accessible environment are not violated for waste package containment times as short as 300 years and fluxes that are 40-times the upper bound of 0.5 millimeter (0.02 inch) per year (see Section 6.3.1.1 for calculation of ground-water travel times to the accessible environment and Section 6.4.2 for estimates of releases of radionuclides to the accessible environment).

At this time, no plausible scenarios have been developed that suggest earthquakes, faulting, or volcanic activity is likely to lead to unacceptable releases of radionuclides.

Conclusion

On the basis of presently available data and interpretations for the Yucca Mountain site, the rates and magnitudes of tectonic processes during the Quaternary Period were relatively low. No mechanisms have been identified whereby the expected tectonic processes or events could lead to unacceptable radionuclide releases. Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition for postclosure tectonics (level 3).

6.3.1.7.7 Plans for site characterization

During site characterization, field investigations will continue to evaluate the tectonic activity of the Yucca Mountain site and surrounding region. These investigations will include (1) more trenching, including trenching parallel to scarps as well as across scarps, to evaluate possible strike-slip motion, (1a) search for obscure fault scarps with low sun-angle aerial photography, (1b) more detailed geomorphic studies of the faults using state-of-the-art structural geomorphology techniques; (2) monitoring of earthquake activity at the site and in the surrounding region; (3) monitoring of ground motion in drill holes; (4) precise monitoring of geodetic positions and elevations; (5) more studies of geomorphic history during the Quaternary Period; (6) additional measurements of in situ stress in drill holes and underground workings; (7) compilation of various types of structural syntheses of the geology of the Nevada Test Site (NTS) region; (8) compilation of combined geologic maps of Yucca Mountain showing detailed Quaternary fault distribution together with detailed distribution of Quaternary stratigraphic units; (9) compilation of earthquake epicentral plots by fractional magnitude intervals to evaluate conceptual models of the seismic quiet zone southeast of the NTS. In addition, more data on the geohydrologic system will be obtained, which will enable the local ground-water system to be modeled in detail. This modeling will then permit the effects of credible tectonic events on ground-water flow and radionuclide transport to be described.

6.3.1.8 Human interference technical guideline (10 CFR 960.4-2-8): Natural resources (10 CFR 960.4-2-8-1) and site ownership and control (10 CFR 960.4-2-8-2)

6.3.1.8.1 Introduction

This guideline contains two qualifying conditions. One is for the natural resources guideline, and one is for the postclosure site ownership and control guideline. The postclosure site ownership and control guideline is discussed in Section 6.2.1.1.

The qualifying condition for this guideline is as follows:

The site shall be located such that--considering permanent markers and records and reasonable projections of value, scarcity, and technology--the natural resources, including ground water suitable for crop irrigation or human consumption without treatment, present at or near the site will not be likely to give rise to interference activities that would lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.

The human interference technical guideline consists of the natural resources and postclosure site ownership and control technical guidelines. The guideline on natural resources addresses general concerns about surface and subsurface resources, including minerals, energy resources, and ground water. It considers these resources with respect to reducing or removing the incentives for economically motivated postclosure human-interference activities that could adversely affect the isolation capabilities of a site. The guideline on site ownership addresses the requirements of the Nuclear Regulatory Commission for the U.S. Department of Energy to obtain ownership and surface and subsurface rights to land and minerals within the controlled area of the repository. This section evaluates the Yucca Mountain site against the overall qualifying condition for human interference and against the conditions of the natural resources guideline. Section 6.2.1.1 provides relevant data and the evaluation with respect to the site ownership and control guideline.

The natural resources guideline contains two favorable conditions, five potentially adverse conditions, two disqualifying conditions, and one qualifying condition. The site ownership and control guideline contains one favorable condition, one potentially adverse condition, and one qualifying condition. Table 6-37 summarizes the evaluations for the natural resources guideline, except the disqualifying conditions. See Section 6.2.1.1 for the summary table for site ownership and control.

6.3.1.8.2 Data relevant to the evaluation

The energy- and mineral-resource potential of Yucca Mountain and surrounding areas has been evaluated by Bell and Larson (1982) and by Quade and Tingley (1983). Boreholes have been drilled in and around Yucca Mountain for the Nevada Nuclear Waste Storage Investigations Project (Maldonado and Koether, 1983; Spengler et al., 1981; Scott and Castellanos, 1984), and core samples and drill cuttings have been routinely analyzed by geochemical

Table 6-37. Summary of analyses for Section 6.3.1.8; human interference technical guideline (10 CFR 960.4-2-8): natural resources (10 CFR 960.4-2-8-1) and site ownership and control (10 CFR 960.4-2-8-2) (see Table 6-2)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITIONS	
(1) No known natural resources that have, or are projected to have in the foreseeable future, a value great enough to be considered a commercially extractable resource.	The evidence indicates that this favorable condition is present at Yucca Mountain: no present or projected uranium, hydrocarbon, or critical mineral resources have been identified; potential development of ground water for irrigation is not expected because of unsuitable topography and great depth of water table.
(2) Ground water with 10,000 parts per million or more of total dissolved solids along any path of likely radionuclide travel from the host rock to the accessible environment.	The evidence indicates that this favorable condition is not present at Yucca Mountain: ground water has total dissolved solids less than 300 parts per million.
POTENTIALLY ADVERSE CONDITIONS	
(1) Indications that the site contains naturally occurring materials, whether or not actually identified in such form that (i) economic extraction is potentially feasible during the foreseeable future or (ii) such materials have a greater gross value, net value, or commercial potential than the average for other areas of similar size that are representative of, and located in, the geologic setting.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: no critical or unique energy, metallic, or nonmetallic resources have been identified in the site vicinity. There is no credible potential for the use of water resources for agriculture.

Table 6-37. Summary of analyses for Section 6.3.1.8; human interference technical guideline (10 CFR 960.4-2-8): natural resources (10 CFR 960.4-2-8-1) and site ownership and control (10 CFR 960.4-2-8-2) (see Table 6-2) (continued)

Condition	Department of Energy (DOE) finding
(2) Evidence of subsurface mining or extraction for resources within the site if it could affect waste containment or isolation.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: no evidence of subsurface mining or extraction for resources has been found at the site.
(3) Evidence of drilling within the site for any purpose other than repository-site characterization to a depth sufficient to affect waste containment and isolation.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: there has been no drilling at the site except for evaluation for the potential repository.
(4) Evidence of a significant concentration of any naturally occurring material that is not widely available from other sources.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: resources in the site vicinity are also found outside the vicinity where they are more abundant and can be extracted more economically.
(5) Potential for foreseeable human activities--such as ground-water withdrawal, extensive irrigation, subsurface injection of fluids, underground pumped storage, military activities, or the construction of large-scale surface-water impoundments--that could adversely change portions of the ground-water flow system important to waste isolation.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: ground-water development for irrigation is not expected because of unsuitable topography and great depth to the water table. If extensive withdrawal of ground water lowered the water table, improved waste isolation would result because of increases in unsaturated zone travel times. Limited energy and mineral resources limit the potential for human activities.

Table 6-37. Summary of analyses for Section 6.3.1.8; human interference technical guideline (10 CFR 960.4-2-8): natural resources (10 CFR 960.4-2-8-1) and site ownership and control (10 CFR 960.4-2-8-2) (see Table 6-2) (continued)

Condition	Department of Energy (DOE) finding
QUALIFYING CONDITION	
<u>Human interference: natural resources</u>	
<p>The site shall be located such that--considering permanent markers and records and reasonable projections, of value, scarcity, and technology--the natural resources, including ground water suitable for crop irrigation or human consumption without treatment, present at or near the site will not be likely to give rise to interference activities that would lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.</p>	<p>Available evidence does not support the finding that the site is not likely to meet the qualifying condition (level 3): no known valuable natural resources are present, and potential for future natural resources is low; permanent markers are expected to remain effective and discourage future human interference.</p>
<u>Human interference: site ownership and control</u>	
<p>See Table 6-2 for second human interference qualifying condition which is the qualifying condition for postclosure site ownership and control.</p>	

methods. Field exploration and geologic mapping have been conducted by the U.S. Geological Survey (Christiansen and Lipman, 1965; Lipman and McKay, 1965; Scott and Bonk, 1984). Archaeological surveys have been conducted in the site area to detect historical evidence of resource extraction activities (Pippin et al., 1982; Pippin, 1984).

Geothermal resources in the area were inventoried by Garside and Schilling (1979), and evaluated by Trexler et al. (1979). The hot springs studied are northwest and south of the Yucca Mountain site. Data from the site-specific investigations were compared to the general requirements in White (1973) in order to determine geothermal resource potential. Detailed discussions of the potential for energy and mineral resources, including assumptions and data uncertainties, are presented in Section 3.2.4.

A ground-water resource potential map has been prepared by Sinnock and Fernandez (1982). Data on water quality in the site vicinity have been obtained by Benson et al. (1983) and Winograd and Thordarson (1975). The regional ground-water flow model for the site is discussed in Section 3.3.2, which also includes discussions of ongoing work.

6.3.1.8.3 Favorable conditions

(1) No known natural resources that have or are projected to have in the foreseeable future a value great enough to be considered a commercially extractable resource.

Evaluation

Present knowledge of the status of energy resources at or near the site suggests that (1) there is no potential for any commercially attractive geothermal or hydrocarbon resources at or near Yucca Mountain and (2) there is no indication of uranium resources at Yucca Mountain. The energy resources appraised by Bell and Larson (1982) include hydrocarbons (e.g., oil, gas, oil shale, and coal); low- to moderate-temperature sources of geothermal energy; and radioactive minerals (i.e., uranium and thorium). None of the project boreholes have shown evidence of the presence of energy or mineral resources (Maldonado and Koether, 1983; Spengler et al., 1981; Scott and Castellanos, 1983). The area around Yucca Mountain is extremely well known in terms of heat flow. Hot springs and wells were inventoried and evaluated by Garside and Schilling (1979) and Trexler et al. (1979). Data from more than 60 wells (some as deep as 1,800 meters (6,000 feet)) is available, and water temperatures range from 21 to 65°C (70 to 149°F). With present technology, this temperature range is insufficient for commercial power generation, which requires temperatures of at least 180°C (350°F) (White, 1973). Specific mineral resources appraised include base and precious metals (e.g., silver), as well as significant industrial minerals and rock materials (e.g., gravel). Detailed information supporting this evaluation is presented in Section 3.2.4, and a resource map is shown in Figure 6-23.

Although ground water is used for irrigation in Ash Meadows and in the Amargosa Valley, it is unlikely to be used for irrigation at Yucca Mountain because of the rugged terrain and great depth to the water table (Sinnock and Fernandez, 1982). Supporting data for this evaluation are given in

Figure 6-23. Location of metallic ore deposits, industrial minerals, thermal waters, and mining districts in the vicinity of Yucca Mountain. Modified from Bell and Larson (1982) and Trexler et al. (1979).

Section 3.6.3.3, which discusses the uses and sources of water in the Amargosa Desert. Other pertinent information can be found in the hydrology (Section 6.3.3.3) and socioeconomics (Section 6.2.1.7) guidelines.

Conclusion

There are no known natural resources that have, or are projected to have in the foreseeable future, a value great enough to be considered commercially extractable. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(2) Ground water with 10,000 parts per million or more of total dissolved solids along any path of likely radionuclide travel from the host rock to the accessible environment.

Evaluation

Most samples of ground water obtained to date from wells and springs throughout the region, including the Yucca Mountain area, have total-dissolved-solids (TDS) concentrations of less than 300 parts per million (Benson et al., 1983). Winograd and Thordarson (1975) report a TDS value of 886 parts per million for Well J-11 in Jackass Flats. Thus, ground water with 10,000 parts per million or more of total dissolved solids probably does not occur along any flow path.

Conclusion

Reported analyses of local ground water indicate that it is unlikely that the total dissolved solids could reach or exceed 10,000 parts per million in the ground water along any path of likely radionuclide travel from the host rock to the accessible environment. Therefore, the evidence indicates that this favorable condition is not present at Yucca Mountain.

6.3.1.8.4 Potentially adverse conditions

(1) Indications that the site contains naturally occurring materials, whether or not actually identified in such form that (i) economic extraction is potentially feasible during the foreseeable future (ii) or such materials have a greater gross value, net value, or commercial potential than the average for other areas of similar size that are representative of, and located in, the geologic setting.

Evaluation

Resource-potential surveys of the region (Bell and Larson, 1982; Quade and Tingley, 1983) are explained in Section 3.2.4 (and briefly discussed under the favorable condition of this guideline). No energy, metal, or non-metal resources unique to the site vicinity or critical to foreseeable national needs have been identified. The resources identified within the site vicinity are of lower value than similar resources in surrounding regions. On the basis of the preliminary information discussed in sections

3.2.4.2 and 3.2.4.3, Yucca Mountain is not considered to have any potential for the development of natural resources under foreseeable economic conditions and extraction techniques. As pointed out under potentially adverse condition 2, Section 6.3.1.1 (Geohydrology), some water resources are present. However, depths to ground water, topographic conditions, soil unsuitability, and land-use restrictions at the repository site limit the availability and attractiveness of this ground-water resource now and in the future.

Conclusion

Yucca Mountain has no energy or mineral resources for which economic extraction is potentially feasible in the foreseeable future. No resources are known to be present at Yucca Mountain that have greater commercial potential than other areas in its geologic setting. The site does not possess water resources that would meet the criteria stated in the potentially adverse condition. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(2) Evidence of subsurface mining or extraction for resources within the site if it could affect waste containment or isolation.

Evaluation

The resource-potential survey of the region did not identify any evidence of significant mining-related operations at the Yucca Mountain site. The entire area has been mapped by the U.S. Geological Survey, and no evidence of significant subsurface mining has been reported. There is little likelihood that unknown excavations other than shallow prospecting pits exist at the site.

Conclusion

There has been no subsurface mining or extraction for resources at Yucca Mountain. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(3) Evidence of drilling within the site for any purpose other than repository-site evaluation to a depth sufficient to affect waste containment and isolation.

Evaluation

Before waste storage investigations began, two boreholes existed in the area of the proposed site: Well J-13, which is 7 kilometers (4 miles) south-east of the site, and Well J-12, which is approximately 15 kilometers (9 miles) to the northeast. The site is in an area of federally controlled lands, most of which were restricted in the early 1950s to prevent public access. Furthermore, the entire area has been mapped by the U.S. Geological Survey. Consequently, there is little likelihood that unknown wells, boreholes, or excavations other than shallow prospecting pits exist at the site.

Conclusion

There has been no drilling at Yucca Mountain except that for evaluation of the potential repository site. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

- (4) Evidence of a significant concentration of any naturally occurring material that is not widely available from other sources.

Evaluation

The resource-potential survey found no indication of material or resources that are unique to the site or critical to national needs (see favorable condition 1 for this guideline). Significant mineralization does not generally occur within the type of volcanic rock present in the area of Yucca Mountain. Furthermore, the survey indicated that any material resources found in the site vicinity are also found outside this area. Those outside the area typically have more economic value or are more easily extractable.

Conclusion

There is no evidence of any significant concentration of potentially valuable natural resources at Yucca Mountain that are not widely available from other sources. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

- (5) Potential for foreseeable human activities--such as ground-water withdrawal, extensive irrigation, subsurface injection of fluids, underground pumped storage, military activities, or the construction of large-scale surface-water impoundments--that could adversely change portions of the ground-water flow system important to waste isolation.

Evaluation

The potential for extensive ground-water extraction at or near the site is evaluated in detail in potentially adverse condition 2 of Section 6.3.1.1 (Geohydrology). Although potable ground water is present beneath Yucca Mountain, future generations are not likely to drill and extract water from the top of Yucca Mountain, because drilling and extraction would be easier and more economical in the surrounding area. Extensive pumping of Well J-13, which is 7 kilometers (4 miles) southeast of the Yucca Mountain site in Jackass Flats and draws water from the tuffaceous aquifers, has not resulted in measurable regional declines in the water table. This suggests that ground-water extraction in Jackass Flats would not likely induce significant changes in the ground-water flow system. Furthermore, extensive pumping and drawdown of the water table would improve the isolation potential of the site because it would increase the thickness of the unsaturated zone, resulting in longer travel times to the accessible environment. The depth of the water table and rock conditions at Yucca Mountain would make underground pumped-storage schemes uneconomical. Also, because of the low energy- and mineral-potential of the Yucca Mountain site, it is considered unlikely that any commercial or industrial development that would use water, or require subsurface

injections of fluids, would be located in the area. No military activities that affect the ground-water system are foreseen.

Conclusion

The Yucca Mountain area has very limited potential for the large-scale development of any kind of water resources; consequently, modification of the ground-water flow system is unlikely. Water use or waste-fluid production by commercial resource development is not likely in the area. Furthermore, any changes that increase the thickness of the unsaturated zone are likely to be favorable to waste isolation. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

6.3.1.8.5 Disqualifying conditions

A site shall be disqualified if--

(1) Previous exploration, mining, or extraction activities for resources of commercial importance at the site have created significant pathways between the projected underground facility and the accessible environment, or;

Evaluation

Thorough examination of the Yucca Mountain site and comprehensive searches of literature and mining claim files have disclosed no evidence of ground-disturbing activities. Searches have included the following:

1. Archaeological field surveys over more than 28 square kilometers (11 square miles) for historical artifacts, prospects, or other indicators of resource extraction at the site (Pippin et al., 1982; Pippin, 1984).
2. A resource-potential survey including searches of mining literature and claim files for records of past interest in, or activity at, the site (Bell and Larson, 1982; Quade and Tingley, 1983).
3. Geologic mapping of the entire area by the U.S. Geological Survey (Christiansen and Lipman, 1965; Lipman and McKay, 1965; Scott and Bonk, 1984).

It is extremely unlikely that unknown excavations exist at the site. The site is in an area of federally controlled lands, most of which were restricted in the early 1950s to prevent public access and thereby excluded from the development of even small-scale mining operations.

Conclusion

There have been no previous exploration, mining, or extraction activities for resources at the Yucca Mountain site. No significant pathways have been created between the projected underground facility and the accessible environment. Therefore, on the basis of the above evaluation, the available evidence does not support a finding that the site is disqualified (level 1).

- (2) Ongoing or likely future activities to recover presently valuable natural mineral resources outside the controlled area would be expected to lead to an inadvertent loss of waste isolation.

Evaluation

As described in Chapter 3, Bell and Larson (1982) investigated the resource potential around Yucca Mountain and identified no energy, metal or nonmetal resources unique to the site vicinity or critical to foreseeable national needs. Figure 6-23 shows the location of metal deposits, industrial minerals, and thermal waters in the vicinity of Yucca Mountain. Minor amounts of uranium have been reported west of Yucca Mountain at Bare Mountain, but no uranium mines or prospects have been developed. The nearest mining activity is about 5 kilometers (3 miles) west of Yucca Mountain. Industrial minerals are being extracted from shallow mines in that area.

Conclusion

Only shallow mining of industrial minerals now exists in the vicinity of Yucca Mountain. No resources have been identified that would be likely to cause increased mining activities. There are no ongoing or expected future activities to recover presently valuable natural mineral resources outside the controlled area that could be expected to lead to inadvertent loss of waste isolation. Therefore, the evidence does not support a finding that the site is disqualified (level 1).

6.3.1.8.6 Evaluation and conclusion for the qualifying condition on the natural resources part of the postclosure human interference technical guideline

Evaluation

A thorough examination of the resource potential for Yucca Mountain has been made, including geologic mapping of the area and a resource-potential survey. These studies indicate no known natural resources or naturally occurring materials that currently have significant commercial value. Furthermore, they have not identified any resources or materials that are likely to become commercially attractive in the future. Evidence of subsurface drilling, mining, or exploration has not been found. Extensive groundwater withdrawal near or at the site would be likely to improve the isolation potential by increasing the travel times to a deeper water table.

Permanent markers that would warn future generations of the danger of the repository can be installed at Yucca Mountain. Furthermore, some of the characteristics of the site, such as the extremely arid climate and the low population density in the surrounding region, are favorable to the preservation of permanent markers. No site-specific factors that would be likely to compromise the effectiveness of such markers have been identified, and none are likely to be present.

Conclusion

Currently, the Yucca Mountain site has no known valuable natural resources, and no natural resources have been identified that are likely to become sufficiently valuable in the foreseeable future that they would encourage interference activities that could lead to unacceptable releases of radionuclides. The only resource of value is ground water, and extensive withdrawal could favorably affect portions of the ground-water flow system important to isolation by increasing the thickness of the unsaturated zone. Extreme aridity and low population density help to guarantee that an effective system of permanent markers can be installed. Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition for postclosure human interference (level 3).

6.3.1.8.7 Plans for site characterization

The effects of ground-water withdrawal in various parts of the area surrounding the Yucca Mountain site will be better established by hydrologic information collected during site characterization. Additional data on hydraulic gradients and relationships among ground-water basins and sub-basins will be particularly useful for refining regional hydrologic models. The need for additional information on resource potential will be evaluated during site characterization.

6.3.2 POSTCLOSURE SYSTEM GUIDELINE (10 CFR 960.4-1)

6.3.2.1 Introduction

The qualifying condition for this guideline is as follows:

The geologic setting at the site shall allow for the physical separation of radioactive waste from the accessible environment after closure in accordance with the requirements of 40 CFR Part 191, Subpart B, as implemented by the provisions of 10 CFR Part 60.

The geologic setting at the site will allow for the use of engineered barriers to ensure compliance with the requirements of 40 CFR Part 191 and 10 CFR Part 60.

The postclosure system guideline defines general requirements for the performance of the entire waste disposal system after the repository has been closed. These performance requirements are based generally on the objective of protecting the health and safety of the public until the radioactivity of the waste has decreased to safe levels (i.e., 1,000 years) and specifically on the requirements of the U.S. Environmental Protection Agency (EPA) 40 CFR Part 191 (1985) and the Nuclear Regulatory Commission (NRC) 10 CFR Part 60 (1983).

The waste disposal system consists of a natural barrier subsystem (the geologic setting at the site) and an engineered barrier subsystem (the waste package and the mined repository excluding boreholes, shafts, and seals). The role of engineered barriers as part of the total waste disposal system is recognized by both the EPA and the NRC; both of these agencies have established specific performance requirements or objectives in 40 CFR Part 191 (1985) and 10 CFR Part 60 (1983), respectively. However, the objective of the siting guidelines is to ensure the selection of a site that has the required capability for waste isolation. For this reason, the merits of the geologic setting at the site have been evaluated independently from any engineered features that would be used, and engineered barriers have been considered only where necessary to establish a reference condition for evaluating the potential effectiveness of particular site conditions (Section 6.4.2).

At this stage of site investigations, the data that have been collected and analyzed are insufficient for assessing the performance of the total waste disposal system, its subsystems, and components or the uncertainties associated with each component. Such an assessment will be conducted after site characterization and the final design of the repository have been completed. Therefore, final conclusions about the ability of the Yucca Mountain site to comply with the postclosure system guideline are neither possible nor expected at present. It is, however, possible to make judgments, based on the quantitative and qualitative evaluations reported in this section, about the degree of confidence that the site will indeed be shown to comply with the system guideline after site characterization.

6.3.2.2 Evaluation of the Yucca Mountain site

The approach used in evaluating the Yucca Mountain site against the postclosure system guideline is both quantitative and qualitative. The quantitative approach predicts the quantity of radionuclides that would be released from the repository into the accessible environment during the next 10,000 years if present site conditions persist. The assumption about present conditions persisting in the future is necessitated by the unavoidable uncertainty about specific future conditions at Yucca Mountain (or any site). The predictions are based on limited information about the site and simple modeling techniques. Their sole purpose is to establish the general range of expected site performance.

The qualitative approach balances the potential influences of the favorable and the potentially adverse conditions in the technical guidelines. This approach is judgmental because the relative importance of particular favorable and potentially adverse conditions must be weighed in relation to their potential effects on the behavior in the context of the overall setting at Yucca Mountain. Nonetheless, evaluations of the site against these conditions can strongly indicate whether a site has the features needed for long-term waste isolation.

The data on which the quantitative and qualitative analyses are based are summarized in sections 6.3.1.1 through 6.3.1.8. The analyses of Sinnock et al. (1984) and Thompson et al. (1984) supplement the analyses in this

section and provide additional detail. Sinnock et al. (1984) and Thompson et al. (1984) also used early estimates of ground-water flux (Sass and Lachenbruch, 1982) and estimates of matrix diffusion (Travis et al., 1984) in some of their calculations.

6.3.2.2.1 Quantitative analyses

In Section 6.4.2, the predicted performance of simple system and sub-system models is informally compared with six regulatory criteria specified by the U.S. Environmental Protection Agency (EPA) (40 CFR Part 191, 1985) and the Nuclear Regulatory Commission (NRC) (10 CFR Part 60, 1983): the waste-containment requirements of 40 CFR 191.13, the individual protection requirements of 40 CFR 191.16, the ground-water protection requirements of 40 CFR 191.16, the ground-water travel time specified in 10 CFR 60.113, the performance objective for the waste package specified in 10 CFR 60.113, and the fractional radionuclide-release rate from the engineered barrier system specified in 10 CFR 60.113 (see Table 6-51 in Section 6.4.2). The comparison shows that the Yucca Mountain site, as described by the simple model discussed in Section 6.4.2, would meet all of these criteria. In regard to the isolation requirements of 40 CFR 191.13, the cumulative release of radioactivity (in curies) to the accessible environment for the first 10,000 years after repository closure is predicted to lie well below the EPA limits for a wide range of the fractional radionuclide-release rates from the engineered-barrier system. As a corollary, releases to the saturated zone under Yucca Mountain are predicted to be zero for the first 10,000 years, and the modeled system meets the ground-water protection requirements of 40 CFR 191.16. The expected ground-water travel time is greater than 10,000, with an average travel time of 43,405 years; hence the modeled system also meets the performance objective of a 1,000-year pre-waste-emplacement ground-water travel time in 10 CFR 60.113. The lifetime of the model waste package is expected to exceed 3,000 years, which is substantially longer than the performance objective (300 to 1,000 years) of 10 CFR 60.113. Finally, for the upper bound flux estimate, time-averaged fractional radionuclide release rates from the engineered barrier system are predicted to be 1 part in 100 million per year or less, which is only one-thousandth of the limit specified in 10 CFR 60.113, a release of 1 part in 100,000 of the waste species present 1,000 years after repository closure.

Other analyses that supplement the conclusions presented here have been made and described in detail by Thompson et al. (1984) and Sinnock et al. (1984). Thompson et al. (1984) completed their study before evidence became available that the upper bound on flux of ground water at the repository level is probably 0.5 millimeter (0.02 inch) per year (Section 6.3.1.1.5). They chose a vertical flux through the repository of 5 millimeters (0.2 inch) per year as the midpoint of the flux range (1 to 10 millimeter (0.04 to 0.4 inch) per year) suggested by early studies of Sass and Lachenbruch (1982). The release of radionuclides into this flux was assumed to begin 300 years after waste emplacement. The release rate was assumed to be determined by an overall waste-dissolution rate of one part in 100,000 per year of the total mass of the waste (in the form of both spent fuel and high-level waste converted to borosilicate glass). Sorption was the only retardation

mechanism assumed to affect radionuclide transport in the moving water. In this study, only two radionuclides, carbon-14 and technetium-99 (both nonsorbing), were predicted to reach the accessible environment (at that time, this was a point 10 kilometers (6.2 miles) horizontally distant from the repository) within 10,000 years. The estimated quantities released from 1,000 metric tons of heavy metal (MTHM) were about 1 curie of carbon-14 and 8 curies of technetium-99. The release limits established by the EPA for these nuclides in 40 CFR Part 191 (1985) are 100 and 10,000 curies per 1,000 MTHM, respectively. Thus, the early quantitative analysis of Thompson et al. (1984) indicated that the site, in and of itself, could limit radionuclide releases to the accessible environment to about 2 percent of those allowed by the EPA standards provided that flow was in the rock matrix.

More recently, Sinnock et al. (1984) analyzed the sensitivity of releases (both from the waste form and to the accessible environment) to variations in the water flux through the repository and to waste-form solubility. Their results indicate that the Yucca Mountain site would comply with the established EPA release limits even if the water flux reached 20 millimeters (0.8 inch) per year; assuming that radionuclide releases from the waste forms are limited by the solubility of uranium oxide and glass and the phenomenon of matrix diffusion (Travis et al., 1984) retards transport in fractures by a factor of at least 100, and perhaps 400. The results of this study also suggest that the NRC limits for the fractional radionuclide release rate from the engineered barrier system can be met without any engineered barriers other than the waste form because the amount of water likely to be in contact with the waste is insufficient to cause higher rates of waste dissolution.

Three conclusions can be derived from the study by Sinnock et al. (1984). First, flux values up to 40 times the current upper bound of 0.5 millimeter (0.02 inch) per year are not expected to cause releases to exceed limits. Second, the unsaturated zone is favorable for waste isolation because waste dissolution is limited by low flux. Third, geochemical retardation (sorption) is not necessary to satisfy performance objectives, and hence the presence of a zeolitized zone beneath the repository horizon provides additional assurance that radionuclide release and transport will not occur even under extreme conditions. However, the study did rely on the phenomenon of matrix diffusion to meet standards at the higher values of flux.

The performance studies summarized above are first steps toward developing confidence in the waste-isolation capability of the geologic setting at Yucca Mountain. They do not substitute for the detailed performance assessment that will be made after data from site characterization become available. These preliminary studies have used analytical and computational tools that are considered valid and reasonable, but have not all been formally validated and verified. Furthermore, these preliminary studies have not considered disruptive events and processes that could alter the expected pattern of waste release (i.e., climatic changes, tectonism, erosion, and human interference). Although some discussion of disruptive events is given in Section 6.4.2, a complete set of disruptive-event scenarios pertinent to Yucca Mountain cannot be identified until site

characterization is completed. Many of the favorable and potentially adverse conditions in the guidelines deal with potentially disruptive events. The evaluations in sections 6.3.1.1 through 6.3.1.8 summarize the knowledge, some of which is quantitative, that has been gathered about them.

To compensate for uncertainties caused by limited information about the site and the design of the repository, many of the assumptions used in these preliminary studies are conservative. In particular, the following conservative assumptions should be noted:

1. In some of the studies, no credit was taken for engineered barriers in evaluating the performance of the repository, even though a realistic evaluation cannot be made without considering the contribution of engineered barriers.
2. In some of the studies, the percentage of the total water flux passing through the repository that actually reaches and dissolves the waste was assumed to be much higher than is likely (see the discussion of the geohydrology disqualifying condition in Section 6.3.1.1.5).
3. In all of the studies, a uniform vertical downward flux at the repository level was assumed. No consideration was given to the possible diversion of some or of all the percolating water along the generally longer, horizontal flow paths by stratigraphic or structural features in the rock units below the repository.
4. In some of the earlier studies, the thickness of the unsaturated, highly sorptive tuffaceous beds of Calico Hills was assumed to be only 100 meters (330 feet) for the calculations of flow time and radionuclide transport. However, the thickness of the Calico Hills unit below the proposed repository horizon is 100 to 350 meters (330 to 1,150 feet) (see Figure 6-2).
5. None of the studies took credit for the potential drying effect of heat emitted by the waste on the rocks around the waste-emplacement holes or on water entry into waste disposal containers (see the discussion of the geochemistry second favorable condition in Section 6.3.1.2.3).

In combination, the results obtained using these conservative assumptions lend confidence to the conclusion that, after site characterization, the Yucca Mountain site will be shown to meet the postclosure system guideline (10 CFR 960.4-1(a), 1984).

6.3.2.2.2 Qualitative analysis

The evaluations against the favorable and potentially adverse conditions of the postclosure technical guidelines show that the Yucca Mountain site remains eligible under all of the postclosure technical guidelines and is not disqualified under any of the five postclosure guidelines that contain a disqualifying condition (sections 6.3.1.1 through 6.3.1.8). Conclusions about

site suitability will be reevaluated after site characterization, when additional site data and design information are available. These preliminary evaluations lead to different levels of confidence about compliance with each postclosure guideline. The level of confidence is the highest for meeting the guidelines on erosion, dissolution, and human interference; it is only slightly lower for the guidelines on geochemistry and rock characteristics. The potential of the site to meet the guidelines on geohydrology, climate change, and tectonics engenders the most uncertainty. In no instance, however, is the level of confidence low enough to justify a finding that Yucca Mountain does not qualify, or is disqualified, with respect to any of the technical guidelines.

Remaining uncertainties in evaluations of the site against the postclosure technical guidelines stem from the scarcity of data, incomplete understanding of certain natural phenomena, and inability to quantify the likelihood of human intrusion in the distant future. Generally, the more important of these uncertainties are the potential for rapid ground-water flow through fractures and for large rises in the water table in the presence of other potentially adverse conditions at the site. The principal natural phenomena for which incomplete understanding leads to uncertainty are ground-water flow, expected climatic changes, oxidizing conditions in the unsaturated zone, and tectonic processes. These and other phenomena that might significantly affect waste isolation are evaluated in the appropriate sections in this chapter. The implications of the potential effects on waste isolation are not fully understood at present, although certain preliminary observations can be made.

Oxidizing conditions around the waste might seem to indicate an increased potential for releases of radionuclides from the engineered barrier system, although these conditions are not expected to cause serious problems (see discussion of potentially adverse condition 3 in Section 6.3.1.2.4). On the other hand, the current information about the water flux and geochemical retardation at Yucca Mountain suggests that they will decrease the potential for releases of radionuclides to the accessible environment. As discussed below, the low flux expected for the unsaturated zone at Yucca Mountain would increase travel times and limit waste-dissolution rates to extremely low levels. The presence of engineered waste disposal containers would provide additional assurance that the oxidizing conditions, in particular, will not result in unsatisfactory performance.

The possibility of adverse effects due to tectonic activity can be examined by studying their effects on ground-water flow. The parametric analyses by Sinnock et al. (1984) included evaluations of performance under ground-water fluxes of up to 20 millimeters (0.8 inch) per year, which is at least 40 times higher than the maximum flux expected at and below the repository level. Even such high fluxes did not cause the predicted releases of radionuclides at the accessible environment to exceed the proposed U.S. Environmental Protection Agency standards. Current estimates of the most likely flux passing through the host rock at Yucca Mountain indicate that fracture flow is presently not significant and further tectonically induced increases in fracture density in the host rock would not be likely to affect radionuclide migration. Furthermore, the rocks of Yucca Mountain have

been subjected to active tectonism for millions of years and are already highly fractured in the units that are brittle enough to fracture. Therefore, any increase in fracturing is expected to be minor, unless the tectonic regime were to change drastically. Overall, tectonic processes will probably have negligible effects on flow mechanisms in the absence of extreme and rapid climatic changes.

The effects of possible climatic changes represent an area of concern. Possible increases on unsaturated zone flux, increased water table altitudes, and changes in transport processes in both the unsaturated and saturated zones will be carefully evaluated during site characterization. To date, it appears that possible climate changes over the next 10,000 years are unlikely to cause significant changes in the potential for radionuclide releases to the accessible environments.

Human intrusion might seem to present a potential for release of radionuclides that would exceed the regulatory limits. In principle, the presence of potable ground water beneath the site may induce future generations to drill near the repository site to obtain water. However, no mechanisms whereby this drilling could significantly change the total amount of waste released to, or transported by, the hydrologic system have been identified to date. Moreover, concern about the potential for human intrusion is diminished by the great depth to the water table.

In summary, the hydrologic conditions alone are believed to be sufficient to compensate for the potentially adverse conditions outlined above. Other favorable conditions for rock characteristics, erosion, and human interference reinforce the belief that the waste-isolation capabilities of Yucca Mountain are not likely to be seriously impaired in the future.

Therefore, even though Yucca Mountain possesses some potentially adverse conditions, the current understanding of these conditions leads to the conclusion that they will not cause significant risks for future generations. This conclusion must be more firmly established by quantitative analyses of both the likelihood (when possible) and the consequences of the potentially adverse conditions. In addition, the satisfactory performance inferred from the presence of the favorable conditions currently thought to exist at Yucca Mountain must be confirmed with more comprehensive analyses. Proceeding in parallel with site characterization, such analyses would identify the most important conditions for consideration and provide a documented and realistic assessment of the risks posed by a repository at Yucca Mountain.

6.3.2.3 Summary and conclusion for the qualifying condition on the postclosure system guideline

Preliminary quantitative performance studies support the conclusion that a repository at Yucca Mountain qualifies for site characterization under the postclosure system guideline, 10 CFR 960.4-1(a) (1984), because it would meet the U.S. Environmental Protection Agency standards in 40 CFR Part 191 (1985)

if present hydrologic, geologic, and geochemical conditions (as presently understood) persist for the next 10,000 years. Furthermore, it is likely that the Nuclear Regulatory Commission limits on release rates from the engineered barrier system (i.e., 1 part in 100,000) could be met. These conclusions were drawn from several independent preliminary quantitative analyses and qualitative judgments based on site conditions.

The effects of potentially disruptive events or processes, such as climate changes, tectonism, extreme erosion, and human interference have not all been addressed by quantitative analyses, but no realistic and likely mechanisms for repository failure through such events or processes have been identified to date. Qualitatively, the Yucca Mountain site is judged to be qualified under all eight of the postclosure technical guidelines and is not disqualified under any of the five guidelines that contain a disqualifying condition. This conclusion is supported by the overall balance between the favorable and the potentially adverse conditions identified at Yucca Mountain. Although the level of confidence about the existence and the effect of individual site conditions does vary, the favorable aspects of a very small water flux and good geochemical retardation contribute to the high degree of confidence about the ability of the geologic setting to isolate the waste. Therefore, the evidence does not support a finding that the site is not likely to meet the qualifying condition for the postclosure system guideline (level 3).

6.3.3 PRECLOSURE TECHNICAL GUIDELINES

This section presents preliminary evaluations of the Yucca Mountain site against the preclosure technical guidelines that require site characterization for the demonstration of compliance. These technical guidelines are related to the preclosure system guideline on the ease and cost of repository siting, construction, operation, and closure (10 CFR 960.5-1(a)(3), 1984). They are concerned with surface and rock characteristics and hydrologic and tectonic conditions.

6.3.3.1 Surface characteristics (10 CFR 960.5-2-8)

6.3.3.1.1 Introduction

The qualifying condition for this guideline is as follows:

The site shall be located such that, considering the surface characteristics and conditions of the site and surrounding area, including surface-water systems and the terrain, the requirements specified in Section 960.5-1(a)(3) can be met during repository siting, construction, operation, and closure.

The surface characteristics technical guideline is one of several preclosure guidelines under the heading entitled ease and cost of construction, operation, and closure. The objectives of this guideline are to ensure that (1) adverse surface characteristics will not require any technology other

than that reasonably available for siting, construction, operation, and closure of a repository, and (2) the associated costs will not be unreasonable relative to other available and comparable siting options.

The concerns to be addressed under this guideline are related primarily to topographic features that control placement of or otherwise impact surface facilities. Special measures may be necessary for repository construction, operation, and closure in sites prone to periodic flooding, located in rugged terrain, or with other adverse surface features.

This guideline consists of two favorable conditions, one potentially adverse condition, and one qualifying condition. The Yucca Mountain site is evaluated with respect to each of these conditions in the following sections, and Table 6-38 summarizes the pertinent findings for these conditions.

6.3.3.1.2 Data relevant to the evaluation

The candidate locations that were evaluated as potential sites for the surface facilities of the repository are on the eastern side of Yucca Mountain (Jackson, 1984). A reference conceptual site was selected for planning purposes (Neal, 1985). The data needed to describe the surface characteristics were obtained primarily from 1:24,000 topographic maps with 6-meter (20-foot) contour spacing (USGS, 1961) and high-resolution aerial photographs (e.g., Figure 2-2). The topographic data were evaluated together with surface hydrography in order to determine the flood potential along the Fortymile Wash drainage basin (Squires and Young, 1984). Geomorphic observations also have been made to determine the relative ages of surfaces and thereby allow an assessment of the general stability of these surfaces during the operational period.

Flood peaks have been estimated for the 100-year, the 500-year, and the regional maximum (most intense) floods for the eastern part of Yucca Mountain and Fortymile Wash (Squires and Young, 1984). The prediction of the regional maximum flood was based on data from floods elsewhere in Nevada and in surrounding states. The water depths predicted for major channels during flood peaks are based on the estimated runoff produced during extreme storm events and the capacity of the drainage system.

Assumptions and data uncertainties

Uncertainty in topographic data originates in the accuracy of the photogrammetric process and field survey data. The accuracy of topographic data requires an evaluation relative to the purposes for which they are used. The reference topographic maps (USGS, 1961) comply with National Map Accuracy Standards and are adequate for preliminary repository planning. The aerial photographs and associated ground-survey control are sufficient to provide the higher-detail maps that will be required for construction. The flood predictions and regional geomorphic interpretations are partly qualitative, but they are based on prevailing scientific methods. No site-specific flood or runoff data are currently available for Yucca Mountain.

Table 6-38. Summary of analyses for Section 6.3.3.1; surface characteristics (10 CFR 960.5-2-8)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITIONS	
(1) Generally flat terrain.	The evidence indicates that this favorable condition is present at Yucca Mountain: surface facilities and access routes will be located in areas with generally flat terrain.
(2) Generally well drained terrain.	The evidence indicates that this favorable condition is present at Yucca Mountain: there is a well-established drainage system; porous alluvial soils are present and the water table is deep; the area will not pond water.
POTENTIALLY ADVERSE CONDITION	
Surface characteristics that could lead to flooding of surface or underground facilities by the occupancy and modification of floodplains, the failure of existing or planned man-made surface-water impoundments, or the failure of engineered components of the repository.	The evidence indicates that this potentially adverse condition is present at Yucca Mountain: arroyo drainage system is subject to short periods of localized flooding during rare extreme storms; potential exists for minor flooding due to sheet flow during infrequent extreme storms, although standard drainage control measures are considered adequate to protect surface and underground facilities.
QUALIFYING CONDITION	
The site shall be located such that, considering the surface characteristics and conditions of the site and surrounding area, including surface-water systems and the terrain, the requirements specified in Section 960.5-1(a)(3) can be met during repository construction, operation, and closure.	Available evidence does not support the finding that the site is not likely to meet the qualifying condition (level 3): surface facilities would be located on the flat eastern slopes of Yucca Mountain; areas are well drained but subject to short periods of localized sheet flow during rare extreme storms.

6.3.3.1.3 Favorable conditions

(1) Generally flat terrain.

Evaluation

The reference conceptual site for the surface facilities of the repository and exploratory shaft is on the eastern side of Yucca Mountain (Neal, 1985). The site is generally flat and covered with alluvium derived from adjacent highlands. The surface slope is less than 5 percent and, in several places, less than 3 percent. Thus, even though terrain directly above the area proposed for the underground facility is rugged with established drainage channels, the surface facilities and access routes would be located in an area of generally flat terrain.

Access to the surface facilities would be provided by rail and highway. Detailed descriptions of the characteristics of these access routes are given in Section 5.3. A major design consideration is protection for the bridge piers and abutments that would be built across Fortymile Wash because large volumes of water and debris move down the wash during severe storms. The necessary drainage control measures are not major, but the bridge piers and abutments must be well designed to ensure protection against damage.

Conclusion

The surface facilities, shafts, and the access routes to them can be located in generally flat areas with slopes of less than 5 percent. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(2) Generally well-drained terrain.

Evaluation

The drainage systems at Yucca Mountain are well developed; they have been identified from topographic maps (USGS, 1961) and aerial photographs. The conditions that contribute to effective and rapid drainage include the porous alluvial soils and the eastward dipping slopes. The average depth to the water table is 500 to 750 meters (1,640 to 2,460 feet) in the Yucca Mountain area (Section 6.3.1.1).

Conclusion

Yucca Mountain has a well-established drainage system. The consistency of slope direction coupled with the evenness of the surfaces, the depth to the water table, and the porous nature of the alluvial soils, suggest that the area will not pond water. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

6.3.3.1.4 Potentially adverse condition

Surface characteristics that could lead to the flooding of surface or underground facilities by the occupancy and modification of flood plains, the failure of existing or planned man-made surface-water impoundments, or the failure of engineered components of the repository.

Evaluation

The current reference location for the surface facility (Neal, 1985) is entirely outside the main-channel flood zones predicted for the 100-year flood (Squires and Young, 1984). Parts of the reference location would be affected by the 500-year and regional maximum floods predicted by Squires and Young (1984). However, these areas can be protected by standard drainage control measures such as channel lining and by diversion during construction. Neither lining nor diversion is expected to be a major cost. Moreover, the repository at Yucca Mountain is not expected to contain any engineered components whose failure could lead to significant flooding of the underground facility.

The washes emerging from Yucca Mountain have generally steep slopes and are capable of moving large volumes of water and debris, including large boulders. The proposed exploratory shaft site in Coyote Wash is within 50 meters (160 feet) of a small colluvial slump debris-flow deposit. Similar deposits are probably present elsewhere at Yucca Mountain, and such depositional sites will be avoided in choosing a location for repository structures and ventilation shafts. These facilities will not be placed in potentially adverse locations; alternatively, drainage control measures will be used. Relocation can be accomplished at minimal cost; if any, likewise, protective measures such as channel lining or diversion are not expected to add significantly to the cost of the repository. There are no nearby existing or planned man-made surface-water impoundments that could flood a repository at Yucca Mountain. The engineered components of the repository are not likely to fail because their design and specifications will be independently examined by the Nuclear Regulatory Commission and adequate safety factors will be used during design, construction, and operation.

The flooding potential predicted for the Fortymile Wash system is based on conditions that can be expected during the rare but extreme meteorological events that occur in the area (Section 6.2.1.4). These predictions are derived from data for similar events in the region. The flood-potential maps are reasonable first estimates that can be used in planning, and the maps will be revised on the basis of additional field geomorphic data. To verify the flooding predictions, field investigations, including the collection of runoff data, are under way. These investigations will include the mapping of areas that were subject to flooding during Holocene time and a calculation of the probable maximum flood (PMF) during site characterization.

Conclusion

The arroyo drainage system leading away from Yucca Mountain is subject to localized flooding and debris flows during rare extreme storms. These storms could result in flooding of the surface or underground facilities due

to possible sheet flow. However, the impacts of this infrequent localized flooding can be mitigated during repository siting, construction, operation, and closure. On the basis of the potential for sheet flow, the evidence indicates that this potentially adverse condition is present at Yucca Mountain.

6.3.3.1.5 Evaluation and conclusion for the qualifying condition on the preclosure surface characteristics guideline

Evaluation

The conclusions about the suitability of the surface characteristics at the Yucca Mountain site are largely qualitative; they are based on the engineering and scientific judgment of the many professional civil engineers and geologists who have examined the available topographic, geomorphic, and flood potential data for the site.

The alluvial area on the eastern side of Yucca Mountain is well drained but also subject to overflows of water from the existing arroyos during extreme storm events (100-year, 500-year, and regional maximum floods). As indicated by their recurrence intervals, these floods are very infrequent and of such short duration that they would not significantly affect the siting, construction, operation, and closure of a repository. The effects of these extreme events, as well as debris flows and sheet flow, can be readily mitigated using standard drainage control measures.

Conclusion

The surface and underground facilities can be located where the surface characteristics would not adversely affect either the ease or the cost of repository siting, construction, operation, and closure. The current reference surface facility location is well drained but may be subject to infrequent floods and sheet flow whose impacts can be mitigated easily using standard drainage control measures without incurring major costs. Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition for preclosure surface characteristics (level 3).

6.3.3.1.6 Plans for site characterization

Site-specific meteorological data will be obtained and should allow better planning for the drainage control measures that are needed to adequately protect the surface and underground facilities. Field investigations and laboratory testing to determine soil and bedrock properties will be conducted to determine improved locations for the repository surface facilities.

6.3.3.2 Rock characteristics (10 CFR 960.5-2-9)

6.3.3.2.1 Introduction

The qualifying condition for this guideline is as follows:

The site shall be located such that (1) the thickness and lateral extent and the characteristics and composition of the host rock will be suitable for accommodation of the underground facility; (2) the repository construction, operation and closure will not cause undue hazard to personnel; and (3) the requirements specified in Section 960.5-1(a)(3) can be met.

The objective of this guideline is to ensure that due consideration is given to the host-rock characteristics that may affect (1) the ease and cost of repository siting, construction, operation, and closure, and (2) the safety of repository workers. Among those characteristics are the thickness and lateral extent of the host rock, geomechanical properties that are favorable for the stability of underground openings, and conditions that allow the construction of shafts and the underground facility with reasonably available technology.

The preclosure rock characteristics guideline consists of two favorable conditions, five potentially adverse conditions, one disqualifying condition, and one qualifying condition. The evaluations reported below are summarized on Table 6-39 for all conditions except the disqualifying condition.

6.3.3.2.2 Data relevant to the evaluation

Summary of available data

Available data indicate that rock with acceptable characteristics for locating an underground facility are present beneath Yucca Mountain (Sinnock and Fernandez, 1982; Sinnock et al., 1986; Mansure and Ortiz, 1984). Detailed surface mapping (Scott and Bonk, 1984) and core samples from drill holes led to the initial identification of four potential horizons for the underground facility; samples from the potential host rock obtained from core samples have been analyzed for mineral content (Bish et al., 1982, 1984) and for geoengineering properties (Lappin, 1980a,b; Lappin et al., 1982; Dravo Engineers, Inc., 1984; Price et al., 1982a,b; Price, 1983). A three-dimensional geologic model of Yucca Mountain is presented in Nimick and Williams (1984). Additional data are available on borehole and tunnel tests and measurements in tuff (Healy et al., 1984; Tyler and Vollendorf, 1975; Ellis and Ege, 1976; and Warpinski et al., 1978).

The relative suitabilities of the four potential horizons have been compared on the basis of minability, excavation stability, maximum capacity for gross thermal loading, far-field thermomechanical responses, and potential ground-water travel times (Johnstone et al., 1984). Geoengineering properties of the four horizons are reported in Tillerson and Nimick (1984).

Table 6-39. Summary of analyses for Section 6.3.3.2; rock characteristics (10 CFR 960.5-2-9)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITIONS	
(1) A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the underground facility.	The evidence indicates that this favorable condition is not present at Yucca Mountain: significant lateral flexibility cannot be claimed until site-characterization data are available.
(2) A host rock with characteristics that would require minimal or no artificial support for underground openings to ensure safe repository construction, operation, and closure.	The evidence indicates that this favorable condition is present at Yucca Mountain: minimal artificial means are required to support similar tuffs at the NTS; a similar approach should ensure safe repository construction, operation, and closure.
POTENTIALLY ADVERSE CONDITIONS	
(1) A host rock that is suitable for repository construction, operation, and closure, but is so thin and laterally restricted that little flexibility is available for selecting the depth, configuration, or location of an underground facility.	The evidence indicates that this potentially adverse condition is present at Yucca Mountain: significant lateral flexibility cannot be claimed.
(2) In situ characteristics and conditions that could require engineering measures beyond reasonably available technology in the construction of the shafts and underground facility.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: shafts and underground facility can be constructed using proven, standard methods.

Table 6-39. Summary of analyses for Section 6.3.3.2; rock characteristics (10 CFR 960.5-2-9) (continued)

Condition	Department of Energy (DOE) finding
(3) Geomechanical properties that could necessitate extensive maintenance of the underground openings during repository operation and closure.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: conventional rock bolts and wire mesh are expected to provide adequate support and require minimal maintenance.
(4) Potential for such phenomena as thermally induced fracturing, the hydration and dehydration of mineral components, or other physical, chemical, or radiation-related phenomena that could lead to safety hazards or difficulty in retrieval during repository operation.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: welded tuff is expected to have sufficient physical and chemical stability to ensure safety and retrievability; no potentially hazardous physical, chemical, or radiation-related phenomena have been identified.
(5) Existing faults, shear zones, pressurized brine pockets, dissolution effects, or other stratigraphic or structural features that could compromise the safety of repository personnel because of water inflow or construction problems.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: an unsaturated zone repository is not expected to have water in flow, and stratigraphic and structural features are not expected to compromise safety.

QUALIFYING CONDITION

The site shall be located such that (1) the thickness and lateral extent and characteristics and composition of the host rock will be suitable for accommodation of the underground facility; (2) repository construction, operation, and closure will not cause undue hazard to personnel; and (3) the requirements specified in Section 960.5-1(a)(3) can be met.

Available evidence does not support the finding that the site is not likely to meet the qualifying condition (level 3): thickness and lateral extent of host rock is expected to provide adequate, but not significant flexibility for the lateral layout and reasonable flexibility for vertical repository positioning; no rock characteristics that could cause undue hazards to personnel have been identified or are expected to be encountered.

Ground support requirements have been evaluated using mining experience at tunnel excavations on the Nevada Test Site (NTS) in formations similar to the devitrified, densely welded tuffs of the Topopah Spring Member at Yucca Mountain (Dravo Engineers, Inc., 1984; Tibbs, 1985; Ortego, 1985). Small-diameter-heater experiments have been conducted in tuff at one of these excavations to determine the thermomechanical rock properties (Zimmerman, 1983).

Information from Kendorski et al. (1984) is used to evaluate the long-term stability of shotcrete lining in tunnels. Accident statistics from the hardrock metal-mining industry and from the Nevada Test Site excavations are used in the discussion of operational safety (Schueler, 1985). Information on accident experience in tunnels at the NTS is available in Dunnam (1985) and Tibbs (1985). The concepts of the safety orders presented in DOE (1981) and the California Department of Mines safety orders have been incorporated into the safety standards and enforcement practices now used for tunnel construction at the NTS.

Assumptions and data uncertainties

The analyses of the suitability of rock characteristics are based primarily on data from surface reconnaissance and boreholes. No major excavations have been made at the Yucca Mountain site, and there is no experience with excavations in the proposed horizon elsewhere in the area. However, extensive tunnel systems have been excavated in the bedded and welded tuffs at Rainier Mesa on the NTS. As part of the Nevada Nuclear Waste Storage Investigations Project, in situ experiments have been initiated in one tunnel in Rainier Mesa (G-Tunnel) in a welded tuff unit with some characteristics that are similar to those expected in the repository horizon. Data collected from drill holes have been used in the preliminary stability analysis for the proposed exploratory shaft (Hustrulid, 1984) which will penetrate the potential repository horizons. Data obtained from the exploratory shaft and related boreholes will significantly expand the existing data base that is being used for conceptual design of the repository and design analyses. As part of the preliminary conceptual design and related work, a study was made addressing how variations in geologic and geophysical properties impact repository planning and design (Dravo Engineers, Inc., 1984). New information obtained during site characterization may lead to some changes in the design of the repository, but these changes are expected to be within the limits expressed in the original reference repository design (Jackson, 1984). The thermomechanical modeling of the potential repository horizons (Johnstone et al., 1984) is considered a preliminary evaluation. Validation of this model and additional modeling will be addressed during site characterization. The degree of confidence in both the existing data for the site and the analyses made with the data is considered more than sufficient for a preliminary evaluation against the preclosure guideline on rock characteristics.

6.3.3.2.3 Favorable conditions

- (1) A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the underground facility.

Evaluation

Flexibility in locating the repository is important because sufficient options should be available to construct the underground facility away from areas of geologic anomalies, should they be found. No anomalies are expected, except for minor faults and associated breccias. None of these are likely to have significant adverse affects on mine stability. Flexibility related to waste emplacement in horizons other than the Topopah Spring Member was discussed in Section 6.3.1.3 (Postclosure rock characteristics). This evaluation examines emplacement only in the part of the densely welded, devitrified Topopah Spring Member that contains less than 15 to 20 percent lithophysae.

The primary area for locating the underground facility is shown as area 1 on Figure 6-24. Area 1 contains relatively few faults and rare fault breccias. Available data indicate that rock with acceptable characteristics is present in area 1, and could be present in area 2 and perhaps outside these areas (Sinnock and Fernandez, 1982; Mansure and Ortiz, 1984). On the basis of detailed surface mapping by Scott and Bonk (1984) of the possible repository expansion areas, area 2 has the greatest potential of containing rock with acceptable characteristics. The surface and subsurface geologic exploration of Yucca Mountain has concentrated on area 1 and the immediately surrounding area.

Analysis of a three-dimensional computer graphics model of Yucca Mountain (Nimick and Williams, 1984) indicates that area 1 contains approximately 890 hectares (2,200 acres), although minor faults and breccia and blocks rotated to steep dips may occupy some of the area. Approximately 749 hectares (1,850 acres) of area 1 are potentially usable on the basis of the disqualifying condition for erosion, which requires a 200-meter (656-foot) overburden. The acreage required for a repository that is designed to accomodate the equivalent of 70,000 metric tons of heavy metal (MTHM) is approximately 616 hectares (1,520 acres) (Mansure and Ortiz, 1984), suggesting that additional acreage outside area 1 may be needed for significant lateral flexibility in repository design. Area 2, a primary area for extending the underground facility from area 1, contains about 910 hectares (2,250 acres) and is similar to area 1 in fault density. Data for area 2 are limited to those obtained from surface mapping and extrapolation of drill hole data obtained mainly in and around area 1. If extension of the underground facility from area 1 is required to provide lateral flexibility, additional geologic characterization will be required to determine how much of this area is usable. Area 3 contains approximately 162 hectares (400 acres). Small portions of this area could violate the disqualifying condition requiring 200 meters (656 feet) of overburden. Area 4 contains approximately 607 hectares (1,500 acres) and also may have rock characteristics similar to the other areas, but fewer data exist for this area.

Portions of area 4 could also violate the disqualifying condition for 200 meters (656 feet) of overburden. Area 5 contains about 202 hectares (500 acres), and area 6 contains 1,072 hectares (2,650 acres). Area 6 has a very complex fault structure with steeply dipping faults, and part of area 6 may not meet the 200-meter (656-foot) overburden requirement.

The repository envelope is conservatively assumed to require 45 meters (148 feet) (Mansure and Ortiz, 1984). Basic requirements for the potential host rock are the presence of sufficient overburden and a sufficient thickness of suitable host rock to contain this envelope. Mansure and Ortiz (1984) show that the approximate thickness of the preferred host rock is on the order of 100 to 175 meters (330 to 575 feet) within area 1. The overburden at Yucca Mountain, as discussed in Section 6.3.1.5 (Erosion), is more than 300 meters (984 feet) over about 50 percent of area 1. In area 1, the thickness of the relatively lithophysae-free part of the densely welded Topopah Spring Member varies greatly; however, it is expected to be more than adequate for locating the underground facility.

To date, a value of 15 to 20 percent has been used to differentiate between the lower portion of the Topopah Spring Member, which is relatively free of lithophysae, and the upper portion, where lithophysae are more abundant. At low percentages, lithophysae have little effect. At high percentages lithophysae could change the thermomechanical properties of the rock, possibly to the point that minability and ground-support requirements may be affected. Although the preferred horizon is expected to have less than 15 to 20 percent lithophysae, this does not imply that the underground facility must be placed in host rock with less than 15 to 20 percent lithophysae, but only that host rock with lower lithophysae content may be preferable. The effect of lithophysae content on thermal properties of the host rock will be investigated during site characterization.

Figure 6-25 shows a cross section, A-A', through area 1 and the possible location of the underground facility. The preferred host rock is near the base of the unit marked Tpt. The basis for choosing this unit and other horizons considered as potential repository horizons are discussed in Chapter 2 and in Section 6.3.1.3 (Postclosure rock characteristics). In locating a preliminary horizon that represents the underground-facility volume, Mansure and Ortiz (1984) considered the dip and thickness of the host rock, the lithophysal content, and overburden requirements. The preliminary choice of horizon, shown in Figure 6-25, may change during site characterization. However, a single surface should be available that will satisfy all current design criteria. The strike and dip of the underground facility envelope (N 11° W, 5° E) will not result in grades too steep for waste-handling equipment. The strike and dip of the surface assumes a 5° east slope and a 1° north slope. Data gathered during site characterization will be used to determine whether the lateral extent of the host rock is sufficient to allow the position of the underground facility to be more nearly horizontal.

Conclusion

The potential host rock at Yucca Mountain is sufficiently thick to provide significant vertical flexibility in the placement of the underground facility. The primary repository area which has to date been the focus of

Figure 6-25. Approximately east-west cross section of primary repository area showing possible location of the underground repository envelope. For approximate location of cross section A-A', see map view in Figure 6-24. Modified from Mansure and Ortiz (1984).

exploration, provides limited lateral flexibility. Contiguous areas appear to have some rock that may be suitable, but additional exploration will be necessary to claim significant lateral flexibility. Therefore, the evidence indicates that this favorable condition is not present at Yucca Mountain.

- (2) A host rock with characteristics that would require minimal or no artificial support for underground openings to ensure safe repository construction, operation, and closure.

Evaluation

Artificial support for underground openings is routinely used to ensure the stability of the openings and the safety of workers. The requirements for such artificial support are estimated by engineering judgment, experience gained from excavating rock types with similar characteristics, and calculations that simulate the expected rock behavior. The analyses and judgments used to support the conclusions of this section were developed from available core-property data, extrapolations based on rock-mass classification techniques, finite-element analyses of the mined openings, and minability assessments.

Techniques for classifying rock masses use compilations of existing underground-support practice, categorized according to parameters recognized as important, to estimate the required support for underground openings. These techniques are extremely useful in the preliminary design or feasibility stages of a project because they allow designers to make rational and generally conservative judgments about expected conditions. The rocks of the Topopah Spring Member have been assigned a range of rock-mass quality values based on available core data. Two widely used classification techniques were applied (Dravo Engineers, Inc., 1984): (1) the Council for Scientific and Industrial Research Classification System and (2) the Norges Geotekniske Institute Classification System. The rock-mass classifications derived from these two systems cover a range of values. A conservative approach to support design was taken by choosing conservative ranges for the input parameters. Given the assumption of a 6-meter (20-foot) span and the classification values, ground-support requirements can be estimated (Dravo Engineers, Inc., 1984) for the full range of expected conditions. The expected support requirements include (1) 2.5- to 3-meter (8- to 10-foot) long fully grouted rock bolts on a 1.5-meter (5-foot) grid spacing with steel wire mesh covering the rock surface for safety; (2) possibly shorter supplemental bolts added on a staggered grid spacing; and (3) in some instances 5 to 7 centimeters (2 to 3 inches) of shotcrete applied to rock surfaces.

There is no direct experience with excavation support requirements in the Topopah Spring Member at Yucca Mountain. However, these support requirements can be compared with experience in similar tuffs at the Nevada Test Site (NTS). The geologists and engineers familiar with tunneling and ground-support requirements for the welded Grouse Canyon Member at G-Tunnel at Rainier Mesa have suggested that the support requirements for the welded Topopah Spring Member at Yucca Mountain are likely to be similar (Ortego, 1985). The ground-support practice experience for the Grouse Canyon Member

has been documented (Ortego, 1985), and consists of 2.5-meter (8-foot) epoxy grout-anchored rock bolts on a 1 by 1.3 meter (3 by 4 foot) spacing, supplemented by wire mesh. For the section of the tunnel that has been documented, Ortego (1985) noted that this support practice has proven to be adequate to date with no stability problems in the three years since tunnel construction.

The estimated ground-support requirements for a repository at Yucca Mountain are considered to be minimal in comparison with the ground support used in similar underground construction projects. For civil works such as tunnels, underground rail stations, and power plants, the support requirements for excavation stability are designed with safety factors that are several times larger than would be used for a mine or temporary excavation. Rock bolts and wire mesh are typically considered to be the minimal support for civil works projects, if for no reason other than worker safety. Major support requirements, such as steel sets or reinforced concrete, are not expected to be required at Yucca Mountain except perhaps in special areas, such as access ramps, shaft openings, and fault zones. The use of rock bolts, wire mesh and, in some instances, shotcrete sprayed on walls has the advantage of easy maintenance over an extended time, further ensuring the stability of mine openings through repository closure.

In estimating the support requirements for a repository, it is necessary to consider variations in room size as well as the stresses and displacements expected to result from the heat emitted by the waste. Variations in room sizes directly affect the stresses around openings. Heat-related stresses caused by waste emplacement have been predicted by numerical-analysis techniques. The preliminary analyses completed to date indicate that the stresses and displacements that are expected to result from the heat emitted by the waste would not lead to significant stability problems in the drifts (Johnstone et al., 1984). Confidence in these analyses is based on mining experience and field tests in similar devitrified, densely welded tuff in G-Tunnel at Rainier Mesa. A conservative design approach might, however, include additional rock bolts along the drift walls to offset the expected lateral expansion of the rock mass in response to the heat.

Long-term stability considerations for excavations in tuff must also include possible detrimental effects of the emplacement environment on the elements of the support system. For the emplacement drifts at Yucca Mountain two such considerations could be important: temperature effects on the rock bolt anchor system or shotcrete and corrosion effects on the rock bolts. The temperature field induced by the waste disposal containers could affect the stability of the epoxies that are used at the NTS to anchor rock bolts. There are several approaches that could be used to deal with this situation, should it be identified as a problem affecting drift stability. One approach would be to use an epoxy with a higher temperature service rating. Other approaches include the use of a full-length-anchored-friction-driven, or expanded bolts (such as Split Sets or Swellex) as well as cement-grouted bolts (grouted dowel or Perfo) and cement-cartridge-anchored bolts developed in Europe where epoxy-anchored bolts are not accepted as part of permanent support. Temperature effects on shotcrete lining, if any are used, would be manifested as strength reductions, particularly following a heating-and-cooling cycle. Kendorski et al. (1984) note that such strength reductions

could exceed 25 percent at 205°C (400°F); they indicate, however, that proper mixture and composition can minimize these effects. Any loss of strength in the shotcrete can be compensated for by an equivalent proportional increase in thickness of the shotcrete.

Corrosion effects on the rock bolts are also a possible consideration in long-term suitability of the emplacement drifts at Yucca Mountain. A steel rock bolt, if subject to condensation or exposure to water vapor, could corrode. Isogalvanic coated and hot zinc-galvanized rock bolts are standard, off-the-shelf products designed to minimize corrosion. It is not clear that zinc-galvanized steel would prevent corrosion in the emplacement environment at Yucca Mountain; in fact, it could enhance corrosion through cathodic behavior of the steel. However, other coatings such as nickel, cadmium, or epoxy would not be significantly more costly than zinc galvanizing and would perform better in inhibiting corrosion. Corrosion is not always detrimental to a bolt-type support system; the friction-anchored or expanded bolts become more effective as the steel corrodes because corrosion effectively increases the friction coefficient. Also, the cement-grouted bolt types are not very sensitive to corrosion, because their anchoring capacity is developed over the full length of the bolt and the grout protects the steel from corrosion.

Final decisions about elements to be used for the ground-support system will consider potential chemical interactions with the waste disposal container components and waste form. Additional thermal and chemical modeling and testing will be completed during site characterization to support final decisions on ground-support requirements.

Conclusion

Excavation experience at the NTS and numerical analyses of the stability of repository-sized openings suggest that an underground facility in the Topopah Spring Member at Yucca Mountain will require minimal artificial ground support for safe construction, operation, and closure. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

6.3.3.2.4 Potentially adverse conditions

- (1) A host rock that is suitable for repository construction, operation, and closure, but is so thin or laterally restricted that little flexibility is available for selecting the depth, configuration, or location of an underground facility.

Evaluation

The requirements for host-rock thickness and lateral extent have been discussed under favorable condition 1 in this section and under favorable condition 1 of Section 6.3.1.3 (Postclosure rock characteristics). These discussions noted that most exploration has been limited to a portion of the Yucca Mountain site that is designated as area 1 in Figure 6-24. In most of the usable portion of area 1, the thickness of the low lithophysal portion of

the potential host rock averages more than 3 times the value (45 meters or 148 feet) used as a conservative estimate of the envelope needed for the underground facility. Such a thickness is judged to provide significant flexibility in selecting the depth of the repository.

The analyses further indicate that area 1 has a usable area of approximately 749 hectares (1,850 acres). Present waste inventories and repository design concepts (Mansure and Ortiz, 1984) indicate that approximately 616 hectares (1,520 acres) is required for a repository. Comparison of these areas shows that the primary area contains slightly more usable area than that required for a repository, but if conditions are found to be unacceptable in some of this area, then flexibility in the lateral placement of the repository could be considered limited. Analysis of existing site data provides confidence that several contiguous areas (areas 2, 3, and 4 in Figure 6-24) could also contain suitable host rock. Area 2, the preferred expansion area, contains 910 hectares (2,250 acres). The suitability of these additional areas can be confirmed only by site characterization.

Conclusion

The host rock at Yucca Mountain is sufficiently thick to provide significant flexibility for selecting the depth of the underground facility. The primary area, which has been the focus of exploration, provides limited flexibility in lateral placement. Site characterization may expand the usable area, thereby allowing flexibility in lateral placement of the repository. However, considering only the primary area, this potentially adverse condition is present at Yucca Mountain.

(2) In situ characteristics and conditions that could require engineering measures beyond reasonably available technology in the construction of the shafts and underground facility.

Evaluation

Detailed ground-stability studies indicate that the Topopah Spring Member has no known in situ characteristics that cannot be successfully controlled by proven mining methods. The rock characteristics, as well as the design layout and development plan, are such that the underground facility can be developed by conventional mining methods (Dravo Engineers Inc., 1984). From the limited work done so far, it appears that mechanical mining could be used for repository construction in the Topopah Spring Member.

As discussed under favorable condition 2, it is likely that the repository drifts and underground openings can be adequately supported by conventional rock bolts and wire mesh. The discussions under potentially adverse condition 5 describe tunneling experience in similar devitrified, densely welded tuffs at Rainier Mesa that support this conclusion. The rock-bolt and wire-mesh support is minimal in comparison with the supports that are used in civil works projects such as highway tunnels or underground power stations. Steel, shotcrete, or both would be used at Yucca Mountain only if underground observations suggest that such support is necessary possibly, for example, at fault-zone intersections or drift intersections. The proposed ground support is within established technology (Dravo Engineers Inc., 1984). Shafts would

be constructed by standard excavation techniques and lined with concrete (Hustrulid, 1984).

Most of the repository would be located more than 200 meters (656 feet) above the water table (Figure 6-26). Experience in tunnels at the Nevada Test Site (NTS) indicates that, if perched water is encountered, the flow will probably be small and should diminish rapidly. Drill holes in and near the site have not identified perched water at elevations above the base of the Topopah Spring Member (Section 6.3.1.1.3).

Conclusion

There are no indications that the in situ conditions and characteristics would require engineering measures beyond reasonably available technology. The shafts and underground facility can be constructed using proven technology and standard methods. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(3) Geomechanical properties that could necessitate extensive maintenance of the underground openings during repository operation and closure.

Evaluation

The potential host rock is more than 200 meters (656 feet) (see Figure 6-19) below the ground surface. At this depth it would not be affected by weathering or surface water. A rectangular underground opening with an arch-shaped roof is expected to provide a stable opening in the Topopah Spring Member. Localized, minor spalling may occur near corners and on walls because of stress relief or the intersection of joints. Johnstone et al. (1984) noted that although modeling suggested that such fractures could develop in G-tunnel, none were, in fact, observed. As shown in Figure 6-25, most major faults occur outside the planned repository boundaries. As discussed under potentially adverse condition 5, the experience in a similar formation at Rainier Mesa suggests that minor fault zones at the Yucca Mountain site could be traversed by using standard mining and ground support technology. However, considerable data from site characterization are required to confirm this conclusion.

The shafts or access ramps of the repository will penetrate the upper members of the Paintbrush Tuff Formation. A study using the Council for Scientific and Industrial Research and the Norges Geotekniske Institute rock-mass classification systems indicated several alternative schemes for ground-support arrangements (Dravo Engineers, Inc., 1984); all of these arrangements use conventional techniques and equipment. The in situ conditions are such that excavation stability can be maintained with conventional rock bolts and wire mesh. This type of ground support requires limited maintenance, and dry conditions in the repository will reduce corrosion problems with the rock bolts or wire mesh and, in poor rock conditions, shotcrete. The use of an arched-roof opening would reduce stress and lends stability to the rock mass, further reducing support-maintenance requirements. Thus, stable conditions should continue through repository closure. Because of the long operating life of the repository (assumed to be

Figure 6-26. Total thickness of unsaturated zone from disturbed zone (located 50 meters (164 feet) below repository midplane) to water table. Modified from Sinnock et al. (1986).

90 years), some maintenance of underground openings will be required. The maintenance would be routine and well within the limits of existing practices and technology. The thermal stresses resulting from heating after waste emplacement are not expected to significantly affect the stability of the mined openings, although some very localized deformation might occur (Section 6.3.1.3).

Conclusion

The geomechanical behavior of the rocks at Yucca Mountain provides an inherently stable condition that will not require extensive maintenance to keep the underground openings in a serviceable condition for the operating life of the repository. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

- (4) Potential for such phenomena as thermally induced fracturing, the hydration and dehydration of mineral components, or other physical, chemical, or radiation-related phenomena that could lead to safety hazards or difficulty in retrieval during repository operation.

Evaluation

Johnstone et al. (1984) have evaluated the stability of underground openings in the densely welded tuff of the Topopah Spring Member, and the response of the tuff to excavation and thermal effects. These preliminary studies included near-field mechanical and thermomechanical finite-element code calculations, rock-matrix property evaluation, and rock-mass classification. They considered the physical, thermal, and mechanical properties specific to the Topopah Spring Member; the existence of individual sets of fractures; and the expected in situ stress. The results were compared with the behavior of existing underground openings in similar devitrified, densely welded tuff at the NTS. The results indicate that (1) the mined openings are expected to remain stable through repository closure, and (2) the effects of thermally induced fracturing are very localized, being limited to the immediate vicinity of the waste emplacement holes and the periphery of the drifts.

Preliminary estimates predict a potential for rock-matrix fracturing in the immediate vicinity of the waste emplacement hole, but this fracturing should extend no more than 10 centimeters (4 inches) into the rock. The potential for block movement along minor joints or faults intersecting the hole wall is currently under investigation. No structural degradation has been observed in two small-diameter-heater tests conducted in tuff at G-Tunnel (Zimmerman, 1983). The effect of localized sloughing of the hole walls on waste retrievability could be minimized by using a steel liner in the waste emplacement hole.

No minerals present in significant quantities in the repository horizon are susceptible to thermally induced dehydration, hydration, or radiation-related phenomena. Bish et al. (1984) summarize the distribution of minerals in the tuffs at Yucca Mountain and state that about 98 percent of the proposed repository host rock is made up of alkali feldspar, quartz, tridymite, and cristobalite, which are not subject to thermally induced dehydration or

hydration. The proposed repository horizon contains 1 percent or less of smectite (Bish et al., 1984) and is generally not zeolitized (Bish et al., 1982). Thus, there is little potential for the hydration or dehydration of minerals that could affect the safety of repository operation or cause problems with waste retrieval. Cristobalite exhibits an alpha-to-beta phase transition between 235 and 260°C (455 and 500°F) in confined tests (Lappin, 1980a), which is reflected by a slight increase in the thermal expansion coefficient. Because of the transformation temperature, this transition would be expected only in the very near-field of the waste disposal container. The thermomechanical studies use thermal expansion coefficients that account for this behavior; they predict no additional rock fracture beyond the 10 centimeters (4 inches) reported above.

Conclusion

The welded tuff at Yucca Mountain is a physically and chemically stable rock that will be little affected by repository conditions. About 98 percent of the potential host rock consists of alkali feldspar, quartz, tridymite, and cristobalite, all of which are nonhydrous minerals. Currently, the rock is fractured, and any additional thermally induced fracturing will be minor and will not create a safety hazard or produce difficulty in waste retrieval, should retrieval be necessary. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(5) Existing faults, shear zones, pressurized brine pockets, dissolution effects, or other stratigraphic or structural features that could compromise the safety of repository personnel because of water inflow or construction problems.

Evaluation

Artificial support for underground openings is routinely used to ensure the stability of the openings and the safety of workers. The requirements for such artificial support are estimated by engineering judgment, experience gained from excavating rock types with similar characteristics, and calculations that simulate the expected rock behavior. The analyses and judgments used to support the conclusions of this section were developed from available core-property data, extrapolations based on rock-mass classification schemes, finite-element analyses of the mined openings, and minability assessments.

The hydrogeologic conditions of the region and site are described in Section 6.3.1.1. Data on water levels in drill holes within and near the site are shown on Figure 6-3. Naturally occurring perched water of any significance have not been identified in existing drill holes, and no pressurized water zones have been encountered. Only very small amounts of water are expected to seep into excavated drifts by gravity drainage.

Even though faults and associated shear zones exist at Yucca Mountain, the preferred repository area is expected to be minable with standard equipment (Dravo Engineers, Inc., 1984) (see favorable condition 2). Rock with similar mechanical properties has been excavated at the G-Tunnel complex in Rainier Mesa using comparable methods of excavation and ground control. Tibbs (1985) has documented tunneling experience in the welded Grouse Canyon Member at G-Tunnel. A nearly vertical fault with at least 1 meter (3 feet)

of vertical displacement was encountered during tunneling activities in the welded Grouse Canyon Member in G-Tunnel. No comments were noted by the mining inspector in his daily log; the lack of comments indicates that tunneling conditions had not varied appreciably. The fault zone was not noted until the tunnel had advanced about 6 meters (18 feet) beyond the fault. The fault brought welded and nonwelded tuff together along a nearly vertical contact; no water influx was noted. The inspection record shows that the area of the tunnel with the fault was initially mined on November 19, 1981. Preliminary 2.5-meter (8-foot) rock bolts were installed in the faulted area on November 20, 1981, and then on February 16, 1982, roughly 3 months later, 5-meter (16-foot) resin-anchored hardening rock bolts were installed on a 1.3 by 1.3 meter (4 by 4 foot) pattern across the back in the area adjacent to the fault. There was no record that the faulted area produced ground-support problems, and no special bolting was installed in the area of the fault. The conclusion drawn by Tibbs (1985) is that the crossing of the nearly vertical fault with at least 1 meter (3 feet) of vertical displacement did not result in the need for any special ground support in excess of the standard methods used in the drift where no faulting occurred.

Because there may be a need to expand the repository boundaries laterally to increase flexibility (see favorable condition 1), Dravo Engineers, Inc. (1984) has evaluated the potential for mining through the faults and fault zones that bound parts of the primary repository area at Yucca Mountain. Limited data show that the boundaries of the primary repository area (area 1) could be traversed using standard mining and support technology. However, considerable site characterization is required to confirm this analysis. According to Dravo Engineers, Inc. (1984) and confirmed by the Rainier Mesa tunneling experience described above, drifts across the minor fault zones found within the primary area can be excavated without using unusual or unsafe construction practices. Increased ground support could be provided in these areas, or in any areas with less stable rock, to further reduce any potential hazard to workers.

Potential Hazards to Excavation Workers

To evaluate the potential hazards to excavation workers at Yucca Mountain, excavation experience in the welded and nonwelded tuffs at the NTS that have been used for weapons-effect testing has been examined. The safety records show that such excavations can be carried out with minimum adverse effects on worker safety. The safety record can be quantified through the use of incidence rates for worker injury that were associated with time away from work. To assess the relative level of safety for tunneling operations at the NTS, the incidence rates for NTS operations can be compared to injury incidence rates for similar mining operations. Such a comparison is presented in Figure 6-27. The industry category that is most similar to excavation conditions in the tuffs at NTS is the category of hard-rock metal mining. The data presented in Figure 6-27 are based upon industry average data compiled by the National Safety Council and data for NTS operations compiled by Reynolds Electric and Engineering Co., the U.S. Department of Energy contractor for excavation operations. The data presented in Figure 6-27 clearly indicate a significantly better safety record for NTS tunneling operations than is typical of industry practice. While the industry average incidence rate is lower now than it was 20 years ago by a

Figure 6-27. Incidence rate of injuries in tunneling operations at the Nevada Test Site compared to industry averages for hard-rock metal mining. Modified from Schueler (1985).

factor of about 2, NTS operational safety record is still lower than the industry average by a factor of about 3. For the past 10 years, NTS practice which heavily emphasizes worker safety, has resulted in an average injury-incidence rate of less than 1 injury per year per 100 employees.

There are several possible reasons for the difference between industry average and observed NTS incidence rates. One possible reason is that safety standards and enforcement practice at the NTS are probably more stringent than is typical of the mining industry. NTS practice incorporates the concepts of Mine Safety and Health Administration, California Department of Mines safety orders, and DOE Order 5480.1 on safety orders (DOE, 1981) and uses the most stringent governing standards from these regulations. Another possible reason is that whereas standard mining practice must be production oriented to be economical, the tunnels at the NTS are designed and constructed for long-term serviceability and stability. Yet another possible reason is that mining operations typically deal with potentially unstable ground conditions because of the emplacement mode of the minerals being excavated. It is not possible to determine from the data in Figure 6-27 the relative importance of these three possible reasons for the difference in safety at the NTS as compared to the industry average. However, it is clear that all or any of these reasons provide support for the conclusion that tunneling in the various tuff formations at NTS, following existing NTS practice, is significantly safer than hard-rock metal mining in the industry as a whole.

Specific excavation experience in G-Tunnel at the NTS is of interest because part of the G-Tunnel experience involves a welded tuff, the Grouse Canyon Member. Engineers and geologists familiar with excavation in the welded Grouse Canyon Member have expressed the opinion that the ground support that will be required in the Topopah Spring Member at Yucca Mountain is likely to be similar to that required in the welded Grouse Canyon Member (Ortego, 1985). Accident experience at G- and N-Tunnels at the NTS for the period between 1975 and 1985 is summarized by Dunnam (1985). Dunnam states that none of the accidents identified in a search of tunnel records could be considered to be caused by unstable ground, faulting, or other such geologically related conditions. He further observes that this is consistent with his recollections of the period between approximately 1965 and 1985 for NTS operational experience. The one accident that involved the falling of a piece of rock was the result of an oversight in barring down loose rock prior to support installation. The accident report in question indicates that this accident probably would not have occurred if the correct NTS mining practice had been followed. It is important to note that the reported activities in the welded Grouse Canyon Member involved tunneling through a fault zone with 1 meter (3 feet) of observed displacement (Tibbs, 1985).

Conclusion

Faults and shear zones that could compromise the safety of repository personnel because of construction problems or water inflow are not expected in the primary repository area at Yucca Mountain. The design and layout of the underground facility will minimize contact with portions of the host rock where minor faults and shear zones are identified. There is no indication that pressurized brine pockets, evidence of dissolution, or significant accumulations of water or toxic gases are present in the repository horizon.

Hence, no other conditions that could compromise the safety of repository personnel are expected. Safety records for excavation in tuffs at the NTS show that such work has been carried out for more than 20 years with an incidence of injuries that is well below comparable industry averages. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

6.3.3.2.5 Disqualifying condition

The site shall be disqualified if the rock characteristics are such that the activities associated with repository construction, operation, or closure are predicted to cause significant risk to the health and safety of personnel, taking into account mitigating measures that use reasonably available technology.

Evaluation

The current data base for the geoenvironmental properties of the potential host rock consists of the results of laboratory tests on core samples from Yucca Mountain and Rainier Mesa (Lappin, 1980a,b; Lappin et al., 1982; Price et al., 1982a,b; Price, 1983). Rainier Mesa and Yucca Mountain are both composed of layered volcanic rocks, and recent measurements on core samples from densely welded tuffs from both sites indicate that the mechanical properties of the rock matrix are similar; however, it should be noted that a large part of G-Tunnel contains nonwelded tuffs. Excavations in G-Tunnel beneath Rainier Mesa and planned excavations at Yucca Mountain are similar with regard to overburden loadings, opening dimensions, and excavation methods. Because of these similarities, field observations, tests and experience in G-Tunnel can be used to support decisions related to the safe construction, operation, and closure of a repository at Yucca Mountain.

The in situ stress state affects the stability of openings. Stress measurements from rock units below the water table at Yucca Mountain were used to calculate ratios of vertical stress to the minimum horizontal stress. The results show ratios of up to 3.1 (Healy et al., 1984), with a mean of 2.2 for 6 measurements and a standard deviation of 0.4. No reliable stress measurements have been made on the unsaturated zone or on the potential host rock. The stress ratios for tuffs in G-Tunnel have a mean of 2.7 and a standard deviation of 1.3 for 67 measurements (Tyler and Vollendorf, 1975; Ellis and Ege, 1976; Warpinski et al., 1978). G-Tunnel is generally supported only with rock bolts and wire mesh. In the more than 10 years of tunnel operation, the stresses have not resulted in problems in opening stability, even when augmented by severe ground motion from nuclear tests in the tunnel.

The selection of densely welded portions of the Topopah Spring Member as the potential repository host rock was based in part on the average thermal and mechanical properties defined for each of the four horizons that were considered (Tillerson and Nimick, 1984). Available data came from approximately 75 thermal conductivity tests, 95 thermal expansion tests, 35 mineralogic and petrologic analyses, 60 mechanical tests on jointed rock samples, and 120 tests of unconfined and 50 pressure-dependent mechanical

properties tests. The average values for the thermal and mechanical properties of the rock in the Topopah Spring Member are given in Table 6-40.

Johnstone et al. (1984) used nonlinear, finite-element analyses of thermomechanical stresses, standard rock-mass classification systems, and linear calculations for mine design and pillar sizing to evaluate the expected stability of openings. Their preliminary results indicate that existing mining technology can be used to develop stable underground openings that will allow repository operations to be safely carried out from construction through closure. The experience gained in G-Tunnel at Rainier Mesa on the Nevada Test Site (NTS) supports this conclusion; it also indicates that only minimal support for the openings (i.e., rock bolts and wire mesh) would be required. Minability assessments (Tillerson and Nimick, 1984), also supported by G-Tunnel experience, indicate that controlled blasting can be successfully used to excavate openings in the densely welded tuff.

The only other significant physical or chemical phenomena known to be associated with rock characteristics are related to ventilation-system design and worker safety. The temperature increases resulting from the emplaced waste are important in designing ventilation systems and in selecting the standoff distance between the drift and the emplaced waste. Excavations at the NTS show that explosive or other hazardous gases are not to be expected. The ventilation system primarily controls dust. Hazards associated with the dust will be mitigated by supplying adequate flow volumes and filters to meet safety requirements. Similarly, estimates of low-level radiation from the naturally occurring radon released during rock excavation will be used in establishing ventilation requirements. Techniques already implemented in the uranium mining industry will be considered. The proper design and operation of a ventilation system based on current technology should readily mitigate dust and radiation concerns.

Tunnel excavation experience in the welded and nonwelded tuffs at the NTS has shown that such excavations can be carried out with minimum adverse effects on the health and safety of workers. The NTS safety record was quantified and compared to safety records in a similar industry (hard-rock metal mining) in Section 6.3.3.2.4. The incidence rate of injuries at the NTS is about a factor of 3 lower than the industry average for hard-rock metal mining (Schueler, 1985).

Conclusion

Applicable laboratory data, field experience with similar excavations, and thermomechanical stress calculations show that activities associated with the construction, operation, or closure of a repository at Yucca Mountain will not cause significant risk to the health and safety of personnel. Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is disqualified (level 1).

Table 6-40. Average thermal and mechanical properties of the Topopah Spring Member^a

Property	Value
Thermal conductivity (saturated), W/m-°C	1.8 $\pm$ 0.4
Thermal conductivity (dry), W/m-°C	1.6 $\pm$ 0.4
Predehydration linear expansion coefficient, $10^{-6}/^{\circ}\text{C}$	10.7 $\pm$ 1.7 (to 200°C)
Transition-dehydration linear expansion coefficient, $10^{-6}/^{\circ}\text{C}$	31.8 (to 300°C)
Postdehydration linear expansion coefficient, $10^{-6}/^{\circ}\text{C}$	15.5 $\pm$ 3.8 (to 400°C)
Young's modulus, GPa	26.7 $\pm$ 7.7
Poisson's ratio	0.14 $\pm$ 0.05
Unconfined compressive strength, MPa	95.9 $\pm$ 35.0
Matrix cohesion, MPa	28.5
Angle of internal friction, degrees	26.0
Matrix tensile strength, MPa	12.8 $\pm$ 3.5
Joint cohesion, MPa	1
Coefficient of friction for initiation of sliding on joints	0.8

^aData from Tillerson and Nimick (1984).

6.3.3.2.6 Evaluation and conclusion for the qualifying condition on the preclosure rock characteristics guideline

Evaluation

The lateral and vertical extent of the potential repository host rock at Yucca Mountain provides reasonable flexibility for the vertical placement of the repository, and somewhat limited lateral flexibility for repository

placement. Current repository design concepts require 616 hectares (1,520 acres), and the primary repository area contains 890 hectares (2,200 acres) of which approximately 749 hectares (1,850 acres) are considered potentially usable. It may therefore be necessary to extend the repository outside the primary area of Yucca Mountain. Current information indicates that standard mining and support technology would be adequate for this expansion.

Previous experience and presently available data (see favorable condition 2) suggest that artificial-support requirements for the proposed excavation would be minimal and would enable work to be performed without undue hazard to personnel and at reasonable cost throughout the entire repository operations cycle, including retrieval, should retrieval be necessary. At present, there is no evidence that the geomechanical properties of the Topopah Spring Member will respond to waste-emitted heat in any way that would lead to hazardous conditions in the repository that could affect worker safety or preclude waste retrievability.

Conclusion

The lateral extent of the potential host rock is adequate, but it has not been demonstrated to provide significant lateral flexibility for locating the underground facility. There is reasonable flexibility for the vertical positioning. Furthermore, information obtained to date suggests that lateral flexibility is likely to be demonstrated during site characterization. Preliminary exploration activities have not identified any rock characteristics that would cause undue hazards to personnel. Repository siting, construction, operation, and closure can be carried out with reasonably available technology. Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition for preclosure rock characteristics (level 3).

6.3.3.2.7 Plans for site characterization

Site-characterization activities will supplement the existing data base, both through exploratory borings, access to the proposed host rock, and additional laboratory tests. Construction phase tests will provide in situ stress data and shaft convergence data that will be used for design and layout of underground facilities. Large-scale tests performed in the potential repository host rock during the in situ phase of exploratory shaft testing will supplement the data base by providing information on the in situ rock conditions as well as effects, such as fracturing caused by stress and temperature. A large-scale heater test is planned to confirm the behavior of the host rock in the very near field where the highest temperatures and stresses will be induced.

6.3.3.3 Hydrology (10 CFR 960.5-2-10)

6.3.3.3.1 Introduction

The qualifying condition for this guideline is as follows:

The site shall be located such that the geohydrologic setting of the site will (1) be compatible with those activities required for repository construction, operation, and closure; (2) not compromise the intended functions of the shaft liners and seals; and (3) permit the requirements specified in Section 960.5-1(a)(3) to be met.

The preclosure hydrology technical guideline is concerned with surface and subsurface water that could affect repository surface and underground facilities during construction, operation, and closure. Surface waters have the potential for flooding the underground facility, access ramps, and shafts; they could also affect the ease and cost of constructing and operating the surface and support facilities, including transportation access routes.

Water will be required for the construction, operation, closure, and decommissioning of the repository. The subsurface hydrologic conditions will have a bearing on the cost and safety of construction, operation, closure, and decommissioning. Subsurface water must not compromise the intended functions of the shaft liners and seals. This guideline relies on technical information similar to that supporting the guideline on geohydrology (Section 6.3.1.1).

This guideline consists of three favorable conditions, one potentially adverse condition, one disqualifying condition, and one qualifying condition. The evaluations reported below are summarized in Table 6-41 for all conditions except the disqualifying condition.

6.3.3.3.2 Data relevant to the evaluation

Water-table altitudes at wells near the potential repository site range from about 730 meters (2,400 feet) along the eastern edge to about 780 meters (2,600 feet) near the northwestern edge, along the ridge crest of Yucca Mountain (Robison, 1984). Hydrologic test holes near Yucca Mountain have been tested at yields ranging from about 6×10^{-4} to 4×10^{-2} cubic meters per second (10 to 600 gallons per minute) (Waddell et al., 1984). Well J-13 has intermittently produced more than 0.04 cubic meters per second (600 gallons per minute) between 1962 and 1983 with no effect on water-table altitude (Thordarson, 1983).

Competing requirements for ground water have been considered. Surface water has not been considered for repository or domestic use, because it is not generally available in this arid region. Well J-13 and the proposed location of repository surface facilities are at the Nevada Test Site. If Yucca Mountain is selected for repository development, a permanent land withdrawal will be necessary, and a reservation of water rights is explicit in the withdrawal (Section 6.2.1.3). Estimates of water withdrawals and

Table 6-41. Summary of analyses for Section 6.3.3.3; hydrology (10 CFR 960.5-2-10)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITIONS	
(1) Absence of aquifers between the host rock and the land surface.	The evidence indicates that this favorable condition is present at Yucca Mountain: the host rock is above the water table.
(2) Absence of surface-water systems that could potentially cause flooding of the repository.	The evidence indicates that this favorable condition is not present at Yucca Mountain: there are no perennial stream channels that could potentially flood the repository; however, rare extreme storms could result in flooding of the repository surface facility and access routes due to sheet flow.
(3) Availability of the water required for repository construction, operation, and closure.	The evidence indicates that this favorable condition is present at Yucca Mountain: sufficient ground water is expected to be available from nearby wells.
POTENTIALLY ADVERSE CONDITION	
Ground-water conditions that could require complex engineering measures that are beyond reasonably available technology for repository construction, operation, and closure.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: the potential repository is above the water table and no significant amounts of ground water are expected; shafts and boreholes are expected to be adequately sealed with available technology.

Table 6-41. Summary of analyses for Section 6.3.3.3; hydrology (10 CFR 960.5-2-10) (continued)

Condition	Department of Energy (DOE) finding
QUALIFYING CONDITION	
The site shall be located such that the geohydrologic setting of the site will (1) be compatible with those activities required for repository construction, operation, and closure; (2) not compromise the intended functions of the shaft liners and seals; and (3) permit the requirements specified in Section 960.5-1(a)(3) to be met.	Available evidence does not support the finding that the site is not likely to meet the qualifying condition (level 3): host rock is above the water table; wells are expected to provide adequate water supply; there are no surface-water systems that could flood the repository or compromise shaft liners and seals; and transient runoff will be adequately handled with routine drainage control measures.

consumption by counties and hydrographic regions are included in a series of water planning reports by the Office of the State Engineer (1971, 1974). These estimates provide a basis for projecting future water requirements in Nevada. Water requirements for the construction, operation, closure, and decommissioning of the repository have been estimated on the basis of the preliminary conceptual designs. The average annual consumption of water for a 32-year period of repository construction and operation is estimated to be about 432,000 cubic meters (350 acre-feet) (Morales, 1985).

Squires and Young (1984) have made predictions for 100-year, 500-year, and regional maximum floods; these predictions, described in Section 6.3.3.1, have been used in estimating the potential for flooding surface and underground facilities. Fernandez and Freshley (1984) evaluated the need for shaft liners and seals. Data on ground-water conditions that are routinely encountered and managed with available technology in mines is given by Loofbourow (1973).

Assumptions and data uncertainties

The altitude and configuration of the water table in the Yucca Mountain area are known relatively well because numerous boreholes penetrate the water table, and water levels have been measured precisely (Robison, 1984). However, few moisture-content values or other hydraulic properties have been measured in the unsaturated zone, whose characteristics are therefore less certain. There is uncertainty about the moisture distribution in the unsaturated zone, which could affect sealing concepts. The occurrence of perched-water zones at Yucca Mountain was considered in the sealing-concepts study (Fernandez and Freshley, 1984), but as explained in Section 6.3.1.1, its likelihood is very low.

Uncertainty regarding flooding potential is discussed in Section 6.3.3.1 (Surface characteristics). The analysis of surface-water systems (favorable condition 2) is covered in Section 6.3.3.1.

Estimates of water use during repository construction, operation, closure, and decommissioning are conservative. The effects of increased ground-water withdrawal on regional ground-water supplies have some uncertainty but are considered negligible. Even if the estimates for repository activities were doubled, the effect on the available water at Yucca Mountain would be negligible.

6.3.3.3.3 Favorable conditions

- (1) Absence of aquifers between the host rock and the land surface.

Evaluation

There are no aquifers between the host rock and the land surface. The potential repository horizon is located in the unsaturated zone, 200 to 400 meters (650 to 1,300 feet) above the water table (Figure 6-2) (Robison, 1984). Even if the basal vitrophyre of the Topopah Spring Member were

included in the repository, the water table still would be over 150 meters (330 feet) below the repository.

There is the potential for perched-water zones between the host rock and the land surface. However, it is unlikely that large perched zones occur because they have not been encountered in drill holes to date (over 30 drill holes have been completed within approximately 10 kilometers (6 miles) of the site).

Conclusion

The potential host rock is above the water table at Yucca Mountain and there are no aquifers between it and the overlying land surface. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(2) Absence of surface-water systems that could potentially cause flooding of the repository.

Evaluation

The reference surface facility location is located entirely outside of the main-channel flood zones predicted for the 100-year flood in the Forty-mile Wash drainage system (Squires and Young, 1984). Some portions of the surface facilities may be in areas that could be affected by the 500-year and regional maximum floods predicted by Squires and Young (1984). A study will be conducted during site characterization to determine the probable maximum flood (PMF) in the vicinity of the site.

The washes on, and draining away from, Yucca Mountain have generally steep slopes and during extreme precipitation events are capable of moving large volumes of water and debris including boulders. Structures and shafts will be located to avoid such large volumes of water and debris. In addition, standard drainage-control measures, such as channel lining and flow diversion, will be used where needed. For additional information, see Section 6.3.3.1.

Conclusion

Surface-water drainage through the arroyo systems feeding Fortymile Wash presents a potential for localized flash flooding and sheet flow during extreme storm events. Some portion of the surface facilities might be located in areas that could be affected by the probable maximum flood (PMF). Therefore, the evidence indicates that this favorable condition is not present at Yucca Mountain.

(3) Availability of the water required for repository construction, operation, and closure.

Evaluation

Estimates of water needed for repository construction and operation are given in Chapter 5. The average annual consumption for a 32-year period of

construction and operation is estimated to be approximately 432,000 cubic meters (350 acre-feet) (Morales, 1985).

Hydrologic test holes near Yucca Mountain have been tested at yields ranging from about 6×10^{-4} to 4×10^{-2} cubic meters per second (10 to 600 gallons per minute) (Waddell et al., 1984). Well J-13 (Figure 6-2), which supplies some local water needs in the southwestern part of the Nevada Test Site has yielded as much as 0.04 cubic meters per second (600 gallons per minute) during pumping tests (Thordarson, 1983). Pumping has lowered the water level in the well only slightly, and effects on the regional ground-water system are probably negligible. The static water level was 728.8 meters (2,391 feet) shortly after the well was drilled in 1962; 18 years later, after long periods of intermittent pumping, the water level was essentially the same, 728.9 meters (2,391 feet) (Thordarson, 1983). The excellent production capabilities of Well J-13, combined with the equally good production from the deep regional aquifers under Yucca Mountain (Section 3.3), suggest that sufficient quantities of water can be produced with negligible lowering of the regional ground-water table. Estimates of other ground-water withdrawals in the region are included in reports of the Office of the State Engineer (1971 to 1974).

Conclusion

The ground-water supplies available from nearby wells will be sufficient to satisfy all requirements during the repository life cycle. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

6.3.3.3.4 Potentially adverse condition

Ground-water conditions that could require complex engineering measures that are beyond reasonably available technology for repository construction, operation, and closure.

Evaluation

Because the potential repository at Yucca Mountain would be located entirely within the unsaturated zone, no significant amounts of ground water will be encountered in the underground workings. Furthermore, tunnels in tuffs below Rainier Mesa at the Nevada Test Site are in an area of greater surface recharge and probably of greater moisture flux in the unsaturated zone than in the proposed repository horizon at Yucca Mountain. Inasmuch as extraordinary mining techniques have not been required at Rainier Mesa, none are expected to be needed at Yucca Mountain.

Substantially more severe ground-water conditions than those expected at Yucca Mountain are routinely encountered and dealt with in mines (Loofbouroow, 1973); therefore, no engineering measures beyond those presently available are likely to be needed. This expectation is based largely on experience.

A study has been made to determine the effects of the unsaturated zone environment on shaft liners and seals. The sealing concepts developed to date are based on data obtained from boreholes. Preliminary calculations of seal performance were based on a conceptual understanding of the hydrogeology and supplemented by information from comparable tuff sequences at Rainier Mesa. Should sealing be required, relatively simple and straightforward solutions are proposed (Fernandez and Freshley, 1984). These include filling drifts and ramps with coarse-grained material, using drains where water seeps are encountered, and using grout if more massive flows occur. For sealing borehole USW G-4 (the principal borehole for the exploratory shaft), which penetrates the proposed repository horizon, the use of zeolite fill, slurry, or grout seals is proposed. The same treatment would be used for nearby boreholes that penetrate the repository horizon or the underlying tuffaceous beds of Calico Hills.

Conclusion

The proposed repository at Yucca Mountain is entirely within the unsaturated zone, and no significant amounts of ground water are likely to be encountered in the underground workings. The ground-water conditions at Yucca Mountain will not require complex engineering measures. Sealing of shafts and boreholes is not expected to present any problems. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

6.3.3.3.5 Disqualifying condition

A site shall be disqualified if, based on expected ground-water conditions, it is likely that engineering measures that are beyond reasonably available technology will be required for exploratory shaft construction or for repository construction, operation, or closure.

Evaluation

The repository at Yucca Mountain would be located 200 to 400 meters (650 to 1,300 feet) above the water table. The evidence collected to date from boreholes indicates a very low potential for encountering significant quantities of perched water during exploratory shaft or repository construction. Because the potential host rock is highly fractured, perched-water zones are not likely to be extensive, and if encountered, the water would quickly drain away. Mines are routinely excavated in environments that are much more severe than those expected at Yucca Mountain. Current engineering and technology are more than adequate to handle the hydrologic conditions that are likely to be encountered during the construction of the exploratory shaft or during repository construction, operation, and closure.

Conclusion

It is highly unlikely that significant amounts of ground water will be encountered during the construction of the exploratory shaft and during repository construction, operation, and closure. Currently available

engineering measures are considered more than adequate to guarantee that no disruption of construction and operation will occur because of ground-water conditions at Yucca Mountain. Therefore, evidence does not support a finding that the site is disqualified (level 1).

6.3.3.3.6 Evaluation and conclusion for the qualifying condition on the preclosure hydrology guideline

Evaluation

The known conditions at Yucca Mountain indicate a benign hydrologic situation with respect to construction, operation, and closure of a repository: the potential host rock is above the water table; nearby wells will provide adequate water for construction, operation, and closure; and no engineering measures beyond those presently available will be required by ground-water conditions. Because of the unsaturated conditions, sealing of drifts is probably unnecessary, and routine sealing methods are expected to be adequate for sealing shafts and boreholes. Although portions of the surface facilities may be located on a 500-year floodplain or within the region affected by the probable maximum flood, existing technology and standard drainage control measures are likely to provide adequate protection. Surface or underground facilities are unlikely to be inundated because of the small volume and transient nature of the sheet flow and flash floods that are typical of arid climatic settings like Yucca Mountain.

Conclusion

The unsaturated zone at Yucca Mountain appears to provide a favorable hydrologic environment for underground facilities, offering no currently recognized conditions that would require complex technology or costly engineering measures. Reasonable drainage control measures will provide adequate protection against sheet flow and flash flooding, and adequate sealing techniques are available. The needed amounts of potable water are available to supply projected repository requirements without affecting regional availability. Therefore, the evidence does not support a finding that the site is not likely to meet the qualifying condition for preclosure hydrology (level 3).

6.3.3.3.7 Plans for site characterization

Flood studies will be conducted to provide information on flash-flood potential at the site and to assist in determining potential locations for repository surface facilities. Tests to verify the behavior of shaft and borehole seals will also be conducted. Additional information about subsurface hydrologic conditions will be obtained during exploratory shaft construction and in situ testing within the potential host rock. Further analyses will be made of the possible impacts of water withdrawal for repository activities on local and regional ground-water systems.

6.3.3.4 Tectonics (10 CFR 960.5-2-11)

6.3.3.4.1 Introduction

The qualifying condition for this guideline is as follows:

The site shall be located in a geologic setting in which any projected effects of expected tectonic phenomena or igneous activity on repository construction, operation, or closure will be such that the requirements specified in Section 960.5-1(a)(3) can be met.

The objective of this guideline is to ensure that a repository site is in a geologic setting in which any projected effects of expected tectonic phenomena or igneous activity will be such that no unreasonable or unfeasible design features are required. The concerns to be addressed under this guideline are ground motion or ground disruption that might cause damage to repository or transportation facilities, injury to personnel, or the interruption of repository operations, including retrievability.

The guideline consists of one favorable condition, three potentially adverse conditions, one disqualifying condition, and one qualifying condition. The evaluations reported below are summarized in Table 6-42.

6.3.3.4.2 Data relevant to the evaluation

Summary of available data

Most of the data relevant to preclosure tectonics are cited in Section 6.3.1.7 (Postclosure tectonics). Information of special interest for the preclosure period includes an overview (Reiter and Jackson, 1983) of a study by the Nuclear Regulatory Commission (NRC, 1985) about probabilistic evaluations of seismic hazards. Reviews of the impacts of earthquakes on underground facilities have been prepared by Pratt et al. (1978, 1979), Carpenter and Chung (1985), Jackson (1985b), and Owen et al. (1980), and a final report from a workshop on ground motion and tectonics issues at the Yucca Mountain site is available (SAIC, 1986).

A number of sources were used to provide a basis for estimating the feasibility of constructing and operating a repository under possible earthquake ground motion and displacement. Doser (1985) estimated the minimum magnitudes at which surface fault rupture is likely in the Great Basin. Jackson (1985a) reviewed the seismic design bases for other nuclear facilities. Meehan (1984), Merritt et al. (1985) and Reed et al., (1979) discuss designs that have been developed to accommodate fault displacements beneath structures. Brown et al. (1981), Owen and Scholl (1981), and DOI (1972) discuss designs that have been employed where tunnels and pipelines cross active faults. The performance of facilities that were designed to accommodate and have experienced strong ground motion or fault movement is reviewed by Zeevaert and Newmark (1956), Rosenblueth (1960), ENR (1985a,b), Murphy (1973), Meehan, et al. (1973), Stratta et al. (1977), and Yanev (1978). Attenuation relationships for ground motion have been computed by Joyner and Boore (1981) and Campbell (1981).

Table 6-42. Summary of analyses for Section 6.3.3.4; preclosure tectonics (10 CFR 960.5-2-11)

Condition	Department of Energy (DOE) finding
<p>FAVORABLE CONDITION</p> <p>The nature and rates of faulting, if any, within the geologic setting are such that the magnitude and intensity of the associated seismicity are significantly less than those generally allowable for the construction and operation of nuclear facilities.</p> <p>The evidence indicates that this favorable condition is not present at Yucca Mountain: the predicted magnitude and intensity of seismicity are expected to be acceptable but not expected to be significantly less than those generally allowable for the construction and operation of nuclear reactors.</p>	
<p>POTENTIALLY ADVERSE CONDITIONS</p>	
(1) Evidence of active faulting within the geologic setting.	The evidence indicates that this potentially adverse condition is present at Yucca Mountain: evidence of active faulting and ground-surface displacement is found within the geologic setting.
(2) Historical earthquakes or past man-induced seismicity that, if either were to recur, could produce ground motion at the site in excess of reasonable design limits.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: historical earthquakes or past man-induced seismicity are not expected to cause ground motion at the site that would exceed reasonable design limits.
(3) Evidence, based on correlations of earthquakes with tectonic processes and features (e.g., faults) within the geologic setting, that the magnitude of earthquakes at the site during repository construction, operation, and closure may be larger than predicted from historical seismicity.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: no evidence exists to suggest that earthquakes larger than those predicted from historical seismicity could occur during repository construction, operation, and closure.

Table 6-42. Summary of analyses for Section 6.3.3.4; preclosure tectonics (10 CFR 960.5-2-11)
(continued)

Condition	Department of Energy (DOE) finding
QUALIFYING CONDITION	
The site shall be located in a geologic setting in which any projected effects of expected tectonic or igneous activity on repository construction, operation, or closure will be such that the requirements specified in Section 960.5-1(a)(3) can be met.	Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): tectonics-induced ground motion at the site is expected to be within reasonable design limits for a nuclear facility; there is about a 1 chance in 10,000 for igneous activity over a 10,000-year period. The projected effects of either tectonic or igneous activity in a 90-year period of repository construction, operation, and closure are not likely to be significant.

Assumptions and data uncertainties

The principal assumption made in predicting the tectonism of the region during the preclosure period (assumed to be 90 years) is that the present nature and rate of tectonic processes, as represented by the historical record, will continue into the near future. The major uncertainties in data are attributable to two factors: the historical record of earthquakes in Nevada is relatively brief, and the regional instrumented seismic network at Yucca Mountain has been operating only since 1978. Other key uncertainties are related to estimating the surface accelerations, velocities, and displacements likely to result from an earthquake of a given magnitude at a specified distance from a surface facility. The relationship between earthquake magnitude and fault length may be different for different types of faults (e.g., normal, oblique, and strike-slip) (Bonilla et al., 1984), making this link tenuous for purposes of earthquake prediction and hazard assessment. Uncertainties are also associated with (1) precise definition of seismogenic zones; (2) statistics of the seismic sources within the zones; and (3) appropriateness of attenuation relationships.

6.3.3.4.3 Favorable condition

The nature and rates of faulting, if any, within the geologic setting are such that the magnitude and intensity of the associated seismicity are significantly less than those generally allowable for the construction and operation of nuclear facilities.

Evaluation

Investigations to date covering a 1,100 square-kilometer (425 square-mile) area around the site have found 32 faults that offset or fracture Quaternary deposits. Quaternary faults have been divided into 3 broad age groups: 5 faults last moved between about 270,000 and 40,000 years ago; 4 faults last moved about 1 million years ago; and 23 faults last moved probably between 2 million years and more than 1.2 million years ago (Swadley et al., 1984). Recurrence intervals that have been published for major earthquakes in the region are reviewed in Section 6.3.1.7.5 and summarized in Section 6.3.3.4.5. The historical earthquake record prior to 1978 shows that, within about 10 kilometers (6 miles) of Yucca Mountain, there were 7 earthquakes; 2 had Richter magnitudes of $M = 3.6$ and $M = 3.4$; magnitudes were not reported for the remaining 5 earthquakes. They were apparently very small or had magnitudes that could not be determined due to instrument problems. Prior to 1978, however, standard errors of most locations were ± 7 kilometers (± 4.2 miles) or more. A local seismic network with significantly increased detection and location capability has recorded 3 microearthquakes in the same area between August 1978 and the end of 1983. The largest magnitude was approximately $M = 2.0$ on the Richter scale (Rogers, 1986).

The peak historic acceleration at a location 20 kilometers (12 miles) east of Yucca Mountain was estimated to be less than 0.1g (Rogers et al., 1977). Using similar methods, the seismic hazard for Yucca Mountain was estimated under the assumption that Yucca Mountain faults are not active.

The U.S. Geological Survey deterministically estimated that the most likely peak acceleration at Yucca Mountain would be approximately 0.4g (USGS, 1984). This acceleration was estimated to result from a full length fault rupture (length, 17 kilometers (11 miles), magnitude 6.8) on the Bare Mountain Fault, which is 14 kilometers (9 miles) west of the Yucca Mountain site. Alternative probabilistic hypotheses (USGS, 1984), formulated on the basis of historical rates of seismicity in surrounding regions, and assumptions that earthquakes can occur anywhere in the region including Yucca Mountain, have resulted in estimates that 0.4g has a return period on the order of 900 to 30,000 years. The range of return periods are derived from the use of two different models for the relationship between maximum acceleration and return period. The probability that 0.4g will be exceeded in 90 years, the assumed duration of the preclosure period, under these hypotheses is estimated to be between 0.003 and 0.1 (USGS, 1984). The probabilistic results discussed by Rogers et al. (1977) and USGS (1984) demonstrate that large uncertainties exist in the evaluation of seismic hazard. Different assumptions regarding the appropriate recurrence model, attenuation relationships, and the identification of specific faults as seismic sources can result in widely different estimates of surface acceleration for a given probability. At this time, it is premature to place much confidence in these estimates, other than using them to provide insight until a more complete assessment can be made of the various input parameters that are required for a probabilistic seismic hazard analysis. The estimates by USGS (1984) are in reasonable agreement with previously published estimates of recurrence intervals for major earthquakes in the region surrounding the Nevada Test Site (NTS) which are on the order of 25,000 years for $M \geq 7$ and 2,500 years for $M \geq 6$. Recurrence intervals estimated for $M \geq 7$ earthquakes for the region south and east of Yucca Mountain are longer than those for the NTS region by about a factor of 7. Until detailed fault studies are completed, it will not be possible to determine which of the recurrence intervals are most appropriate for the faults near Yucca Mountain (see Section 6.3.1.7.5).

There are no present intentions to use the same seismic design procedures for waste repositories as have been required for nuclear power plants. The Nuclear Regulatory Commission (NRC) has indicated that no seismic requirements have yet been established for nuclear repositories (NRC, 1985). They note that all repository structures, systems, and components important to safety will be reviewed to establish appropriate design requirements, and that all requirements will be developed to ensure compliance with 10 CFR Part 60 (1983) and 40 CFR Part 191 (1985). However, in order to establish a consistent interpretation of this favorable condition, seismic design values for commercial nuclear power plants that have been licensed by the NRC were examined (Jackson, 1985a). Because most nuclear plants have been built in the east where peak acceleration estimates are low, this compilation shows that about 90 percent of reactors have a safe shutdown earthquake acceleration value that is equal to or less than 0.20g. It should be noted that design limits of 0.75g and 0.67g for plants licensed in areas of high seismic activity have been accepted (Jackson, 1985a).

A description of the approach to be used in establishing the appropriate seismic design requirements for a repository at Yucca Mountain is outlined in Section 6.3.3.4.5. Using this approach, the seismogenic potential of faults in the area will be established, and the appropriate seismic design values

will be determined. Because the only acceleration estimate presently available is for a fault that is not at or near the site, a conservative position on this favorable condition is appropriate for the Yucca Mountain site.

Conclusion

Preliminary deterministic estimates of the ground motion that could result from the largest earthquake associated with a potentially active fault, 14 kilometers (9 miles) west of the Yucca Mountain site, predict a peak ground acceleration of about 0.4g. Acceleration estimates for ground motion resulting from earthquakes on potentially active faults that are closer to the Yucca Mountain site are not available. With the assumption that 0.20g is the peak acceleration that is generally allowable for nuclear facilities, the probable peak acceleration that will be determined for the Yucca Mountain site is not likely to be significantly smaller than 0.20g. Therefore, the evidence indicates that this favorable condition is not present at Yucca Mountain.

6.3.3.4.4 Potentially adverse conditions

(1) Evidence of active faulting within the geologic setting.

Evaluation

There is geologic evidence of Quaternary faulting in the regional geologic setting of Yucca Mountain. Fault scarps, nearly all small and considerably eroded, are present within the region (Carr, 1984). The area has been mapped and studied in sufficient detail to render it unlikely that important fault scarps are undetected. No confirmed surface displacement younger than 40,000 years had been demonstrated at or near Yucca Mountain at the time of publication of Swadley et al. (1984). New data, available in the form of preliminary thermoluminescence dates, may indicate on the order of 1 to 10 centimeters of fault displacement in the eastern Crater Flat area more recently than about 6,000 years ago (Dudley, 1985) (see also Section 6.3.1.7.4, potentially adverse condition 1). Thermoluminescence is a dating technique that has been used in archaeology, but has not yet been shown to provide reliable dates in geologic applications.

Thirty-two faults within a 1,100 square-kilometer (425 square-mile) area around the site offset or fracture Quaternary deposits. Five faults are thought to have last moved between about 270,000 and 40,000 years ago; 4 faults last moved about 1 million years ago; and 23 faults are thought to have last moved between 1 and 2 million years ago (Swadley et al., 1984). Published data on estimates of recurrence intervals for major earthquakes in the Basin and Range Province are compiled in Section 6.3.1.7.5. For the Nevada Test Site (NTS) region, the recurrence interval for $M \geq 7$ earthquakes appears to be on the order of 25,000 years, and the average for the area north of the NTS appears to be on the order of 7,000 to 10,000 years. For $M \geq 6$, the recurrence interval is reported to be on the order of 2,500 years for the NTS region. It should be noted that wide variability results from using different assumptions and regions in the estimation of recurrence intervals.

Within about 10 kilometers (6 miles) of Yucca Mountain, historical seismic records before 1978 show that 7 earthquakes were recorded; of these, 2 had magnitudes of $M = 3.6$ and $M = 3.4$; magnitudes were not reported for the remaining 5 earthquakes. They were apparently very small, or had magnitudes that could not be determined due to instrument problems. A local seismic network with significantly increased detection and location capability has recorded 3 microearthquakes in the same area between August 1978 and the end of 1983. The largest magnitude (M_L), was approximately $M = 2$ on the Richter scale (Rogers, 1986).

Conclusion

During the Quaternary Period, faulting occurred within 10 kilometers (6 miles) of Yucca Mountain. Historical seismic records and recent seismicity at and near the site indicate that faulting is an ongoing process within the geologic setting. Therefore, the evidence indicates that this potentially adverse condition is present at Yucca Mountain.

(2) Historical earthquakes or past man-induced seismicity that, if either were to recur, could produce ground motion at the site in excess of reasonable design limits.

Evaluation

Calculations for the maximum acceleration expected at Yucca Mountain from ground motion induced by underground nuclear explosions at the NTS give a mean acceleration of $0.061g$ and a mean plus 3 standard deviations of $0.32g$ (Section 6.2.1.5). As discussed in the evaluation of the favorable condition under this guideline, the peak historical acceleration from a natural earthquake at a location 20 kilometers (12 miles) east of Yucca Mountain was estimated to be less than $0.1g$ (Rogers et al., 1977).

Two earthquakes with a magnitude of $M = 6$ have occurred within about 200 kilometers (125 miles) of Yucca Mountain: one occurred in 1908, 110 kilometers (68 miles) southwest of Yucca Mountain, and one occurred in 1966, about 210 kilometers (130 miles) to the northeast (USGS, 1984). If these earthquakes recurred, they would not be large enough or close enough to Yucca Mountain to produce ground motion requiring designs in excess of reasonably available technology.

There are presently no plans to apply the same seismic design procedures to waste repositories that have been required for nuclear power plants. The Nuclear Regulatory Commission (NRC) has indicated that no seismic requirements have yet been established for nuclear waste repositories (NRC, 1985). They note that all repository structures, systems, and components important to safety will be reviewed to establish appropriate design requirements, and that all requirements will be developed to ensure compliance with 10 CFR Part 60 (1983) and 40 CFR Part 191 (1985). However, in order to evaluate this favorable condition, the maximum seismic acceleration values for reactors that have been licensed by the NRC for safe shutdown earthquakes (SSE) were reviewed (Jackson, 1985a). The maximum levels occur in California in high seismic activity zones where the Diablo Canyon reactor has been licensed for an SSE of $0.75g$, and the San Onofre units for $0.67g$.

It is important to note that the safe shutdown requirements for a reactor are not relevant for a repository. The inventory of primary-system cooling water in a reactor must be maintained after a seismic event in order to control core decay heat, prevent meltdown, and prevent potential release of short-lived noble gases or particulates. In a repository, the short-lived isotopes no longer exist, and the heat that will be generated is several orders of magnitude less than that for a reactor. This heat can be contained within the facility without dependence on complex mechanical or hydraulic systems operating after a seismic event. Section 6.3.3.4.5 reviews technology that has been used in other facilities to incorporate designs for both displacement and ground motion from earthquakes. Given the current state of knowledge of the estimates for recurrence rates for large earthquakes in the region which includes the Yucca Mountain site, and the record of historical seismicity within the East-West Seismic Belt, there is no evidence that suggests that ground motion at the site during the preclosure time period is likely to be in excess of reasonable design limits.

Conclusion

If historical earthquakes or past man-induced seismicity were to recur at Yucca Mountain, the resulting ground motion would be within reasonable design limits. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(3) Evidence, based on correlations of earthquakes with tectonic processes and features (e.g., faults) within the geologic setting, that the magnitude of earthquakes at the site during repository construction, operation, and closure may be larger than predicted from historical seismicity.

Evaluation

Two historical earthquakes of magnitude $M = 6$ have occurred within about 200 kilometers (125 miles) of the Yucca Mountain site: one in 1908 at Death Valley 110 kilometers (68 miles) southwest of Yucca Mountain, and one in 1966 about 210 kilometers (130 miles) northeast of the site. Within about 10 kilometers (6 miles) of Yucca Mountain, historical seismic records before 1978 show that 7 earthquakes were recorded: of these, 2 had magnitudes of $M = 3.6$ and $M = 3.4$; magnitudes for the remaining 5 were not reported. They were apparently very small or had magnitudes that could not be determined due to instrument problems. A local seismic network with significantly increased detection and location capability has recorded 3 microearthquakes in the same area between August 1978 and the end of 1983. The largest magnitude (M_L) was approximately $M = 2$ on the Richter scale (Rogers, 1986).

For the purposes of evaluation of this condition, it will be assumed that historic seismicity is representative of the earthquake potential for the Yucca Mountain site for short periods of time, such as the preclosure time frame. This evaluation will; therefore, not consider design events or ground motions that are associated with low-probability scenarios, because the likelihood of a larger-than-historic event is low during the preclosure period.

Given the present status of earthquake-hazard assessment, there is no evidence that earthquakes larger than those observed in the historical records for the geologic setting are likely to occur at Yucca Mountain during the 90-year preclosure period. Published estimates of recurrence intervals for earthquakes are reviewed in Section 6.3.1.7.5, for the region that includes the Yucca Mountain site. Recurrence intervals for $M \geq 7$ earthquakes are reported to be on the order of 25,000 years; for $M \geq 6$, recurrence intervals are on the order of 2,500 years; and, for $M \geq 5$, estimates of recurrence intervals are about 250 years.

Conclusion

Seismicity at the site since 1978 has been manifested by earthquakes with magnitudes less than 2, although larger earthquakes have occurred within the geologic setting. There is no evidence that earthquakes larger than those predicted from historical seismicity within the geologic setting should be expected to occur at the site during the assumed 90-year period of repository construction, operation, and closure. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

6.3.3.4.5 Disqualifying condition

A site shall be disqualified if, based on the expected nature and rates of fault movement or other ground motion, it is likely that engineering measures that are beyond reasonably available technology will be required for exploratory shaft construction or for repository construction, operation, or closure.

Evaluation

Within about 10 kilometers (6 miles) of Yucca Mountain, historical earthquake records before 1978 show that 7 earthquakes were recorded; 2 had magnitudes of $M = 3.6$ and $M = 3.4$; magnitudes were not reported for the remaining 5. They were apparently very small or had magnitudes that could not be determined due to instrument problems. Prior to 1978, however, standard errors of most earthquake locations were ± 7 kilometers (± 4.2 miles) or more. A local seismic network has recorded 3 microearthquakes in the same area between August 1978 and the end of 1983. The largest magnitude (M_L , Richter scale) was approximately $M = 2$ (Rogers, 1986). Two historical earthquakes of magnitude $M = 6$ occurred within about 200 kilometers (125 miles) of the Yucca Mountain site, one in 1908 at Death Valley, 110 kilometers (68 miles) southwest of Yucca Mountain and one in 1966, about 210 kilometers (130 miles) northeast of the site.

Thirty-two faults within a 1,100-square-kilometer (425-square-mile) area around the site offset or fracture Quaternary deposits. Five faults are thought to have last moved between about 270,000 and 40,000 years ago; 4 faults last moved about 1 million years ago; and 23 faults are thought to have last moved between 1 and 2 million years ago (Swadley, et al., 1984). At the time of publication of Swadley et al. (1984), no evidence of offset younger than 40,000 years had been confirmed; recently available, but unevaluated, thermoluminescence dates may indicate on the order of 1 to 10

centimeters of fault displacement in eastern Crater Flat more recently than about 6,000 years ago (Dudley, 1985).

Previously published estimates of recurrence intervals for earthquakes were reviewed in Section 6.3.1.7.5. The region including the Yucca Mountain site is reported to have an estimated recurrence interval for $M \geq 7$ on the order of 25,000 years; for $M \geq 6$, the recurrence interval is on the order of 2,500 years; and for $M \geq 5$, the recurrence interval is reported to be on the order of 250 years. The range of rerupture times for major earthquakes presented in Table 6-36 in Section 6.3.1.7.5 reflects the location of the site on the boundary between two zones with very different levels of seismic activity. One zone is to the south of the site with a very low level of seismicity and very long recurrence intervals for large earthquakes (on the order of 190,000 years for $M \geq 7$ for the region including Las Vegas); the other zone is the region to the north where recurrence intervals are on the order of 7,000 to 10,000 years for $M \geq 7$. The range in estimates of recurrence intervals demonstrates the wide variability that results for differing regions when a wide variety of assumptions are used. At this time, these values can only provide insight regarding possible recurrence intervals for faults near Yucca Mountain. Until detailed fault studies are fully completed, there is large uncertainty regarding the appropriate recurrence intervals for these faults. However, the available data (Swadley et al., 1984; Dudley, 1985; and USGS, 1984) show no evidence to suggest that recurrence intervals would be shorter than on the order of 25,000 years for major ($M \geq 7$) earthquakes. It should also be noted that there is no information currently available on the seismogenic potential of faults at or near Yucca Mountain, so that the occurrence of a magnitude 7 earthquake in the area can neither be anticipated nor can it be ruled out. Although USGS (1984) indicates that fault movement with surface displacements are possible at or near the site, recurrence interval data suggest that earthquakes that are large enough to generate major surface displacements are unlikely for the preclosure time period of less than 100 years. Doser (1985) reports that minimum earthquake magnitudes of 6.0 to 6.5 are required to produce surface breakage in the Intermountain Seismic Belt.

The only available estimate of acceleration at the Yucca Mountain site was made under the assumption that faults at the site were not active. The most likely peak acceleration at Yucca Mountain was deterministically estimated to be approximately 0.4g (USGS, 1984). This acceleration was estimated to result from a full length fault rupture (length, 17 kilometers (11 miles), magnitude 6.8) on the Bare Mountain Fault, which is 14 kilometers (9 miles) west of the Yucca Mountain site. Alternative probabilistic hypotheses, formulated on the basis of historical rates of seismicity in surrounding regions, and assumptions that earthquakes can occur anywhere in the region including Yucca Mountain, can be used to show that 0.4g has a return period on the order of 900 to 30,000 years. The probability of 0.4g being exceeded in 90 years, the assumed duration of the preclosure period, under these hypotheses is estimated to be between 0.003 and 0.1 (USGS, 1984). These values are in reasonable agreement with previous estimates of recurrence intervals for the region. The probabilistic results discussed by Rogers et al. (1977) and USGS (1984) demonstrate that large uncertainties exist in the evaluation of seismic hazard. Different assumptions regarding the appropriate recurrence model, attenuation relationships, and the identification of specific faults as seismic sources, can result in widely

different estimates of acceleration for a given probability. At this time, it is premature to place much confidence in these estimates, other than using them to provide insight until a more complete assessment can be made of the various input parameters that are required for a probabilistic seismic hazard analysis.

Possible effects on the preclosure operation of a repository from earthquakes at or near the site can be considered from the standpoint of the potential for ground motion and the possibility of surface displacement. As discussed in potentially adverse condition 2, nuclear reactors have been designed and licensed by the Nuclear Regulatory Commission with safe shutdown earthquake accelerations of 0.75g and 0.67g in seismically active areas.

Owen et al. (1980) review the seismic design considerations that may be applicable to the underground portion of a repository. Experience with strong ground motion acting on other types of structures also provides useful information. For the underground portion of the repository, evidence is available from a number of mines and tunnels in which earthquake damage at depth is reported to be less than at the surface (Pratt et al., 1978). In a review of the effects of earthquakes on underground facilities, (Carpenter and Chung, 1985), the following tentative conclusions are presented. If fault displacement occurs through a site, damage is inevitable; however, damage from shaking alone is generally confined to facilities located within the epicentral region and may be less than damage to surface facilities at the same site. There is an apparent reduction of amplitude with depth, although seismic data for this observation is reported to be mixed. The frequency content of motion is important to the stability of underground openings, and attenuation relationships should be site specific. Model studies indicate that problems may occur in shafts, particularly with waste-handling equipment. This illustrates the need for detailed assessments of the seismic aspects of shaft designs, hoists, and in-shaft waste-handling equipment. All of the above information will be considered during seismic hazard studies of the Yucca Mountain site. Jackson (1985b) reviewed the literature on damage to underground facilities from earthquakes. He notes that there are numerous observations that underground structures suffer less damage than surface structures during strong shaking motion. Jackson (1985b) qualitatively concludes that the probability of events that are large enough to cause damage is likely to be low (10^{-4} to 10^{-5} per year) for the preclosure repository time frame. He also points out that damage to subsurface facilities is likely to be localized so that few waste disposal containers would be affected, although systems used for retrieval, such as the shaft, hoist, and transportation systems may require careful consideration regarding seismic design requirements in support of the Carpenter and Chung (1985) conclusions reviewed above. In general, damage is not likely to occur unless the underground facility is very close to an earthquake epicenter. The primary cause of earthquake-induced failure in underground excavation is apparently movement along preexisting faults or collapse at the portal of a tunnel or shaft.

Seismic designs to accommodate fault displacements have been developed for other facilities including large buildings. The effects of fault displacement on the performance of structures may depend on whether the faults are parallel or perpendicular to building walls and on the thickness and characteristics of soil above bedrock (Meehan, 1984). Merritt et al. (1985)

point out that although the absolute amplitude of displacement may be large, this displacement is often spread over a long length, and that the amount of distortion at any point is generally small, often within the elastic deformation capacity of the structure. State-of-the-art technology allows designs that incorporate flexible joints so that the effects of minor fault movement can be accommodated. Critical areas of a structure could also be isolated by a sand cushion or other displacement accommodating materials (Meehan, 1984).

The questions raised in design and licensing for a waste-handling building (WHB) that spans a surface displacement are significant. A preferable design solution for the geologic setting of Yucca Mountain will be to locate the WHB, which will contain the surface inventory of spent fuel and high-level waste, on a location where surface displacements have not occurred. This building location need be only 152 meters (500 feet) square. Because of the juxtaposition of surface and subsurface facilities at the Yucca Mountain site, there is an extensive area that could be acceptable for the WHB location. Early design studies are intended to establish one or more suitable locations for the WHB where surface fractures are not present. Establishing a suitable WHB location using this philosophy will be preferable to the design and licensing of the facility using seismic design technology described above.

A review of the information available on designs to accommodate fault displacement in non-nuclear facilities shows that many structures have been designed to accommodate offset. For tunnels that cross active faults, an approach used in the California aqueduct where it crosses the Garlock Fault was to design a reinforced concrete conduit; another approach was described for the Bay Area Rapid Transit (BART) System, where tunnels cross the Hayward Fault in Berkeley, California. The Hayward Fault has an estimated annual creep rate of between 6 and 8 millimeters (0.24 and 0.31 inch) per year (Brown et al., 1981). The BART tunnel was oversized and lined with closely spaced steel rib sections to permit absorption of tectonic deformations and promote rapid repair and track realignment (Owen and Scholl, 1981). From experience of damage to underground box conduits during the San Fernando earthquake, suggestions for design of reinforced concrete conduits include the following: close-spaced seismic joints; construction joints and seismic joints placed in the same vertical plane; and avoidance of changes in geometry or properties of the cross section, sudden change of direction, and confluence near an active fault zone. Merritt et al. (1985) suggest a structural design goal that may be appropriate in some cases which is to provide sufficient ductility to absorb the imposed deformation without losing the capacity to carry static loads. The Trans-Alaskan Pipeline was designed to traverse active fault zones having 0.6 meters (2 feet) of horizontal and/or vertical displacement (DOI, 1972). Table 6-43 summarizes information on a number of facilities that have experienced strong ground motion or fault movement.

In the well-known case of the General Electric Test Reactor, located in Pleasanton, California, a comprehensive structural analysis was completed of the safety-related components and systems for both surface displacement and maximum vibratory ground motion. Using an assumption of 1 meter (3 feet) of offset, an analysis of the reactor building suggested that induced stresses in the concrete core structure would be much less than the cracking threshold capacities (Reed et al., 1979).

Table 6-43. Facilities that were designed for and have experienced strong ground motion or fault movement

Facility	Source of Ground Motion	Observed Effects	Reference
Fukushima Nuclear Power Plant, units 1 through 5. Fukushima Prefecture, Japan. Location approximately 125 km from epicenter; 0.12g lateral ground acceleration; 0.25g maximum peak response acceleration of the structures.	Miyagi-Ken-oki, Earthquake June 12, 1978 Magnitude 7.4 Focal depth - 30 km Offshore location	Damage was negligible. Reactors apparently did not shut down and all 5 units were operating 11 days later.	Yanev (1978)
Latino Americano Tower, Mexico City, Mexico. 43 to 44 stories high. Location approximately 350 km from epicenter; 0.05 to 0.1g lateral acceleration (1957); 0.18g acceleration (1985).	Mexico earthquakes July 28, 1957 Magnitude 7.5 Focal depth 25 km September 19, 1985 Magnitude 8.1 September 20, 1985 Magnitude 7.5	Building survived the earthquake without damage.	Zeevaert and Newmark (1956); Rosenblueth (1960) ENR 1985a ENR 1985b
Bunker Hill Tower, Los Angeles, California. 32 stories high; location approximately 25 km from epicenter.	San Fernando Earthquake February 9, 1971 Magnitude 6.4		Murphy 1973
Banco de America, Managua, Nicaragua. 17 stories high. Located immediately adjacent to fault that moved during earthquake; concrete shear wall construction.	Managua, Nicaragua, Earthquake December 23, 1972 Magnitude 6.25	Overall earthquake damage very light. The shear walls exhibited only very minor cracking. Most floors and wall areas exhibited no signs of damage.	Meehan et al. (1973)

Table 6-43. Facilities that were designed for and have experienced strong ground motion or fault movement (continued)

Facility	Source of Ground Motion	Observed Effects	Reference
Tison Building, Cotabato City, Mindanao, Philippines. 4 stories high. Location approximately 100 km from epicenter; moment frame concrete; 0.08 to 0.18g peak acceleration.	Mindanao, Philippines, Earthquake August 17, 1976 Magnitude 7.8 Focal depth less than 33 km.	Survived the earthquake without structural damage and only a slight crack in a concrete block partition.	Stratta et al. (1977)
Bay Area Rapid Transit Tunnel (BART), Oakland, California. Tunnel penetrates Hayward Fault. Designed to accommodate both continuous fault creep and periodic fault displacement associated with earthquakes.	Hayward Fault Creep--6 to 8 mm per year laterally. Historical fault movement (up to 1.5 m) associated with earthquakes in late 1800s.		Brown et al. (1981)

Methodology for assessing significance of seismic and tectonic events

A detailed description of the approach utilized to identify and resolve licensing issues associated with significant seismic and tectonic events is being prepared by the Nevada Nuclear Waste Storage Investigations (NNWSI) Project and will be incorporated in the site characterization plan. Significant seismic and tectonic events are those events that, in light of tectonic history and other characteristics of the site, must be considered in evaluating compliance of the repository with the performance objectives of 10 CFR Part 60 (1983). This description, to be presented as a position paper for discussion with the NRC and the public, will address the formulation of criteria to be used for identifying the significant seismic and tectonic events to be considered for preclosure and postclosure analyses. On a preliminary basis, the position paper will identify scenarios to be addressed in these analyses, including those related to faults at or near the site. A rationale will be developed to explain why certain scenarios should be excluded or included in the analyses on the basis of either probability or consequence. The paper will also evaluate the potential impact of the relevant scenarios on the NRC performance objectives and on underground and surface facility design.

An issue-resolution strategy will also be developed. The specific seismic and tectonic events considered for analysis will be discussed in terms of uncertainties in scenario definition and data and assumptions to be used in analyses. The approach to be used to demonstrate compliance could incorporate several sequential steps. First, the set of release scenarios for the seismic and tectonic events that could affect safety during operation and retrieval would be identified. Next, failure-mode analyses of structures, systems, and components important to safety would be conducted using seismic-initiating-event probabilities and seismic-design parameters determined in accordance with procedures described in the paper. These analyses would be used to determine likely and maximum consequences of failure with respect to radiological safety, considering the ranges of parameters that affect these consequences. The results of these determinations would then be used in an analysis and assessment of the degree of compliance with applicable release limits. Finally, the uncertainty in these analyses and assessments would be evaluated. The resulting information would be used in an evaluation of the impact on design of structures, systems, and components important to safety and to determine the implications regarding the design of structures to resist failure. The above steps will be iterated and will become more sophisticated as data from site characterization becomes available. An iterative approach will also be used to define and refine field programs to obtain the necessary data.

The process just described recognizes that many of the analyses and supporting investigations involve state-of-the-art concepts regarding the acquisition and use of geologic data in sophisticated analyses. While such concepts will be applied for the first time to a repository, the NRC has evaluated numerous probabilistic risk assessments for nuclear reactors, which include seismic initiating events. Techniques discussed above are likely to be similar to those that have been used for probabilistic risk assessments. The analyses, design criteria, and evaluation criteria prepared by the NNWSI Project will be presented in an open forum to ensure that the best technical approaches are incorporated in the subsequent evaluation of the tectonics

disqualifying condition and qualifying condition of 10 CFR Part 960 (1984), the performance objectives of 10 CFR Part 60 (1983), and evaluations of worker and public health and safety.

Conclusion

There may be evidence for a very small amount of surface displacement near Yucca Mountain in the past 6,000 years. The closest historical $M = 6$ earthquake occurred in 1908 about 110 kilometers (68 miles) southwest of the site. Recurrence intervals for earthquakes in the region are reported to be on the order of 25,000 years for $M \geq 7$ earthquakes, and on the order of 2,500 years for $M \geq 6$ earthquakes. On the basis of present knowledge of past earthquakes and fault locations, a review of currently available design technology, and the plans for identifying the significant seismic and tectonics parameters during site characterization, it is judged feasible to construct, operate, and decommission an exploratory shaft facility and a radioactive waste repository at Yucca Mountain. Therefore, the evidence does not support a finding that the site is disqualified (level 1).

6.3.3.4.6 Evaluation and conclusion for the qualifying condition on the preclosure tectonics guideline

Evaluation

The brief historical seismic record at Yucca Mountain shows no earthquakes that have produced damaging ground motion (Rogers et al., 1983; Rogers et al., 1977; USGS, 1984). Within 20 kilometers (12 miles) of Yucca Mountain, the deterministically predicted maximum credible earthquake ($M = 6.8$) on any of the largest of the nearby faults considered seismically active could produce a 0.4g acceleration at Yucca Mountain (USGS, 1984). This earthquake has a predicted return period on the order of 900 to 30,000 years. Published recurrence intervals for earthquakes in the region are reported to be on the order of 25,000 years for $M \geq 7$ earthquakes; on the order of 2,500 years for $M \geq 6$ earthquakes; and, about 250 years for $M \geq 5$ earthquakes. The estimated rupture length of a fault producing an earthquake of a given magnitude and the maximum distance from that fault to a given mean and peak horizontal acceleration are given in Table 6-44. The magnitude-length relationship was derived from western North American earthquakes by Bonilla et al. (1984). The 84th-percentile and mean accelerations of Joyner and Boore (1981) and Campbell (1981) were used to compute conservative estimates of the distances listed in the table. At this time, it has not been determined what percentile will be appropriate for ground motion estimates for a repository. Section 6.3.3.4.5 discusses the methodology that will be used to assess the significance of possible seismic and tectonic events and to establish the required level of conservatism. Additionally, the values presented in Table 6-44 are provided to show a range of peak acceleration values for different sized earthquakes at a variety of distances. Until final evaluations of the faults near the site, appropriate assumptions for fault length, displacement, and earthquake magnitude are not possible or warranted. Table 6-44 shows that to produce peak accelerations in excess of those that have been accepted for reactors would require a large event very close to the site. Given the

Table 6-44. Magnitude vs. fault length and distance from fault to peak horizontal accelerations

Magnitude, M	Fault length, L ^a (kilometers)	Calculation method	Distance to acceleration ^{b,c} kilometers			
			<u>0.2g</u>	<u>0.5g</u>	<u>0.75g</u>	<u>1.0g</u>
5.5	5	(d)	8/17	-/3	-/-	-/-
		(e)	5/8	1/2	-/1	-/-
6.0	9	(d)	12/22	-/7	-/-	-/-
		(e)	8/13	1/3	-/1	-/-
6.5	17	(d)	16/29	2/11	-/-	-/-
		(e)	12/19	2/5	-/2	-/-
7.0	33	(d)	22/38	6/16	-/10	-/5
		(e)	18/28	3/8	-/3	-/-

^aComputed from Bonilla et al. (1984) western North American data. $\log L = 0.566M - 2.44$ where M = surface wave magnitude.

^bThe numbers before and after the slash are the 50th and 84th percentile accelerations, respectively.

^cHyphen (-) indicates that these events are not likely to generate the given accelerations.

^dComputed from Joyner and Boore (1981) 50th and 84th percentile acceleration relationships.

^eComputed from Campbell (1981) 50th and 84th percentile acceleration relationships.

regional estimates of recurrence rates for $M \geq 7$ on the order of 25,000 years and about 2,500 years for $M \geq 6$, the probability of occurrence of a damaging earthquake during the 90-year preclosure period is likely to be very small. Furthermore, the fault lengths observed in the immediate vicinity of Yucca Mountain do not appear sufficient to generate earthquakes with magnitudes greater than 6 or 6.5, regardless of the recurrence intervals. As noted in the evaluation of the disqualifying condition, reasonably available technology should be sufficient to accommodate the seismic design requirements for the site when they are established during site characterization.

From the standpoint of seismic hazard, Reiter and Jackson (1983) point out that an approach based on return periods on the order of 1,000 or 10,000 years have been implicitly accepted by the Nuclear Regulatory Commission (NRC) for developing the seismic design criteria for nuclear reactors. Such an approach may be overly conservative for a geologic repository. The concept of continuing operation of complex systems after a seismic event must be applied to a reactor at the safe shutdown earthquake level, but is not relevant for a repository surface facility. The primary-coolant water supply for a reactor must continue to be available for core cooling after the seismic event. Because of the presence of short-lived isotopes, the fuel in a reactor core will continue to generate decay heat at a rate several orders of magnitude higher than the repository spent fuel. The noble gases xenon and krypton are of particular concern and must be contained along with iodine-131 to protect public health and safety. This requirement necessitates the continued functioning of complex mechanical and hydraulic systems during and after a maximum seismic event as well as the maintenance of the full structural integrity of the containment building. In a repository, the spent fuel or defense high-level waste decay heat is low enough to require only passive systems. Passive dry storage casks are presently before the NRC for licensing for reactor site storage of spent fuel.

After emplacement in the underground facility, waste disposal containers are unlikely to experience velocities or accelerations that approach the velocities and accelerations that will be simulated in drop tests to determine strength for handling purposes. An acceleration of $1g$ at repository depth is extremely unlikely; containers will be designed and tested for impact velocities that produce accelerations of more than 10 times this value.

The volcanic hazard potential at the site from silicic volcanism is much less than that for basaltic volcanism as discussed in Section 6.3.1.7.3. The possible effects and probability of basaltic volcanism at Yucca Mountain during the preclosure period are thoroughly reviewed in sections 6.3.1.7.3 and 6.3.1.7.6. The probability of a recurrence of basaltic volcanism causing disruption of the repository facility ranges between 3.3×10^{-6} and 3.0×10^{-8} for the 90-year preclosure period. Because of the low probabilities and small consequences, the risk posed by basaltic volcanism is judged to be very small during the preclosure period (Link et al., 1982).

Conclusion

The only tectonic activity expected to affect Yucca Mountain during the preclosure period is the occurrence in the surrounding region of small-magnitude earthquakes. Such activity is likely to produce ground motion that

is presently judged to be within the design limits likely to be applied to nuclear repositories and is compatible with the requirements specified in 10 CFR 960.5-1(a)(3) (1984). Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition for preclosure tectonics (level 3).

6.3.3.4.7 Plans for site characterization

During site characterization, field investigations will be continued to further evaluate tectonic activity at the Yucca Mountain site and in the surrounding region (see Section 6.3.1.7, Postclosure tectonics, for a complete discussion). Site-specific attenuation curves will be developed to better predict expected ground motion. Potentially active faults in the area will be carefully evaluated to determine their slip rates and their characteristics.

6.3.4 PRECLOSURE SYSTEM GUIDELINE

The three preclosure system guidelines establish the overall objectives to be met by a repository during repository siting, construction, operation, and closure. They address (1) preclosure radiological safety; (2) the environmental, socioeconomic, and transportation-related effects associated with repository development and operation; and (3) the ease and cost of repository siting, construction, operation, and closure. The first two do not require site characterization for the demonstration of compliance; they are discussed in Section 6.2.2. The third preclosure system guideline does require site characterization; a preliminary evaluation of the Yucca Mountain site against this system guideline is presented in this section.

6.3.4.1 Ease and cost of siting, construction, operation, and closure (10 CFR 960.5-1(a)(3))

6.3.4.1.1 Introduction

The qualifying condition for this guideline is as follows:

Repository siting, construction, operation, and closure shall be demonstrated to be technically feasible on the basis of reasonably available technology, and the associated costs shall be demonstrated to be reasonable relative to other available and comparable siting options.

The preclosure system guideline on the ease and cost of siting, construction, operation, and closure is ranked lowest in importance among the three preclosure system guidelines because it does not relate directly to the health, safety, and welfare of the public or the quality of the environment. The elements pertinent to this guideline are (1) the site characteristics

that affect siting, construction, operation, and closure; (2) the engineering, materials, and services necessary to conduct these activities; (3) written agreements between the U.S. Department of Energy and the affected State, and the Federal regulations that establish the requirements for these activities; and (4) the repository personnel at the site during siting, construction, operation, or closure.

This guideline would not be met if a large number of special measures were necessary because the site had unsuitable surface features; because the host-rock characteristics, including thickness, lateral extent, and geomechanical properties, required technology beyond that available at reasonable cost; because the hydrologic conditions at the site could limit the effectiveness of repository seals or cause flooding in the underground workings; or because the potential for tectonic activity required unreasonable or infeasible design features to protect the workers or the public. Table 6-45 summarizes the finding for the qualifying condition.

6.3.4.1.2 Data relevant to the evaluation

The information presented in this section is derived from those for the technical guidelines on surface characteristics (Section 6.3.3.1), rock characteristics (Section 6.3.3.2), hydrology (Section 6.3.3.3), and tectonics (Section 6.3.3.4). This information is preliminary because the data needed from the site-characterization program are not yet available. Furthermore, only preliminary concepts of the repository design have been identified (MacDougall, 1985). Five important variables are considered in the following evaluation: (1) the location of surface features; (2) the method of access to the underground facility; (3) the depth of the emplacement level; (4) the size and shape of the underground facility; and (5) the method of waste emplacement. These variables will be reevaluated and further refined during the conceptual design of the repository. The conceptual design will, in turn, be evaluated with the information obtained during site characterization. After site characterization, and the completion of a preliminary (Title I) design, more precise estimates of the ease and cost of siting, construction, operation, and closure will be possible.

The discussions that follow describe the activities involved with repository construction, operation, and closure and evaluate each of the three phases in terms of the available technology. It is assumed that 10 percent of the access drifts, emplacement drifts, and holes would be excavated and stabilized during construction and that the remainder would be excavated and stabilized during operation.

6.3.4.1.3 Evaluation

Evaluation for repository siting

Siting activities include: (1) the construction of the exploratory shaft facility; (2) the construction of a secondary egress shaft; (3) the construction of surface and support facilities, including trailers to house offices, medical services, and change rooms, as well as utility systems, head

Table 6-45. Summary of analyses for Section 6.3.4.1; preclosure system guideline: ease and cost of siting, construction, operation, and closure (10 CFR 960.5-1(a)(3))

Condition	Department of Energy (DOE) finding
QUALIFYING CONDITION	
Repository siting, construction, operation, and closure shall be demonstrated to be technically feasible on the basis of reasonably available technology, and the associated costs shall be demonstrated to be reasonable relative to other available and comparable siting options.	Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): no special technology is expected to be required; repository activities are expected to be feasible on the basis of reasonably available technology; site characterization is expected to provide additional information for planning and design.

frames and hoists, ventilation systems, and a road; and (4) laboratory and field studies.

Standard construction and mining practices can be used to construct the exploratory shaft facility. The secondary egress shaft would be raise-bored, a standard mining technique. No unique or nonstandard techniques are expected to be required for the construction of the support facilities or for the conduct of laboratory or field studies.

The surface characteristics that should be considered in siting are mainly the terrain and the surface drainage; both will be carefully considered in the placement of the exploratory shaft facility, secondary egress shaft, and surface support facilities. The surface facilities, shafts, and access routes to them can be located in generally flat areas with well-established drainage systems. No exceptional ground support methods are expected to be required; wire mesh and rock bolts should provide sufficient ground support to provide for worker safety.

Hydrologic factors that should be considered in siting activities are water availability, potential for flooding especially with regard to sheet flow, and ground-water conditions that could require complex engineering measures beyond those reasonably available. Adequate water supplies are available locally. The design and location of the exploratory shaft and support facilities would include plans for adequate protection from sheet flow, which will result from standard drainage control measures. Because the exploratory shaft facility and the secondary egress shaft would be located in the unsaturated zone and because of the aridity of the surface climate, hydrologic impacts on siting are expected to be minimal.

The tectonic factors to be considered in repository siting include the potential for earthquake-induced ground motion that could require engineering measures beyond reasonably available technology during shaft construction. Reasonably available technology is sufficient to design and construct the surface and underground facilities to withstand the maximum potential ground motion likely to occur at the Yucca Mountain site.

Evaluation for repository construction

Construction activities include (1) the construction of surface and support facilities, including waste-handling and treatment buildings, support buildings, head frames and hoists, a railroad, a road, and utility systems; (2) the construction of underground ventilation filter buildings and underground facilities; and (3) the excavation and stabilization of ramps, shafts, drifts, and emplacement holes (MacDougall, 1985).

Standard construction and mining techniques and practices can be used in most of these construction activities. Waste-handling and treatment facilities, as well as ventilation and filtration systems serving waste-emplacement areas, will be designed and constructed in accordance with applicable specifications followed in other nuclear facilities. Activities requiring nonstandard techniques will be carried out in a manner that provides for the safe handling and processing of potentially hazardous radioactive materials under all foreseeable normal and accident conditions.

The surface characteristics that should be considered in construction activities are mainly the terrain and surface drainage, and both will be carefully considered in the design and placement of surface facilities. The pertinent rock characteristics are the thickness and lateral extent of the host rock; the geomechanical properties of the host rock that affect support requirements; thermomechanical characteristics of the host rock that could affect the ease and safety of waste retrieval, should retrieval become necessary, and other rock characteristics that could compromise the safety of workers. Host-rock characteristics will determine the exact depth selected for the emplacement level, and the exact depth would affect the ease and cost of constructing head frames, hoists and skips, ramps and shafts, and the underground facility. The size and the shape of the emplacement area could also affect the cost of mining the drifts.

The hydrologic factors that should be considered in construction activities are water availability, the potential for flooding from sheet flow, and ground-water conditions that could require complex engineering beyond that reasonably available. Adequate water supplies for repository activities are available locally. The design and locations of surface facilities would include standard drainage control measures to ensure adequate flood protection. The unsaturated condition of the host rock and the aridity of the surface climate both contribute to confidence that hydrologic impacts on construction will be minimal.

The tectonic factors that should be considered in repository construction include the potential for earthquake-induced ground motion. The results of studies to date suggest that the maximum potential ground motion at the site will not require construction methods or practices that are beyond reasonably available technology.

Evaluation for repository operation

Operation activities include waste handling, preparation, and emplacement; administration and management; maintenance; mining; and security. Surface characteristics that may affect operation include those that could cause flooding in the surface or underground facilities, or characteristics that could lead to the failure of engineered components of the repository. No problems with flooding are expected for the surface facilities, and designs will include standard drainage control measures to provide protection for both surface and underground facilities. There are several rock characteristics that could affect repository operation. Among them are the discovery that the host rock is too thin or laterally restricted, or the unexpected occurrence of in situ rock conditions that require special engineering measures such as extensive maintenance of underground openings to guarantee worker safety. The rock characteristics related to thermomechanical response are also important in ensuring that waste retrieval could be accomplished safely and without great cost. All evidence to date suggests that an adequate area of the host rock is available, although it is possible that additional lateral area could be useful for added flexibility. The in situ conditions and thermomechanical properties of the host rock would allow safe operation and retrieval, should retrieval become necessary.

During operation, there are two principal hydrologic concerns: an adequate supply of water must be available, and there should be no ground-water conditions that would require complex technology beyond that which is reasonably available. Adequate water supplies are available locally, and the unsaturated host rock would require no special technology.

The tectonic characteristic of the site that could affect repository operation is the potential for ground motion severe enough to disrupt repository operation, causing injury to personnel, or causing an accidental radiation release. The ground motion that is likely to result from natural seismicity or man-induced seismicity can be estimated and operational procedures can be established to protect workers and facilities. A significant impact on operation would be possible only if earthquakes greatly exceeded the seismic design limits of the facilities; conservative design limits would be used (Section 6.3.3.4).

Evaluation for repository closure

The closure of the repository will consist of backfilling drifts, if required, and sealing shafts, ramps, and boreholes. Surface characteristics would affect shaft and ramp sealing, or backfilling if flooding caused disruption of seals or backfill. The rock characteristics that could affect closure activities or potential retrievability include rock instability in waste-emplacement boreholes or drifts. The potential for thermally induced fracturing or other changes in rock properties could lead to safety problems if retrieval were necessary. Standard drainage control measures are sufficient to guarantee that sealing and backfilling will not be disrupted, and all evidence to date suggests that the retrieval of emplaced wastes should offer no mechanical or safety-related problems.

Hydrologic characteristics would be important in closing the repository if flooding occurred or if water were not available for closure or retrieval operations. Ground-water conditions could affect closure and retrieval if complex engineering measures were required because of unexpected conditions. As previously mentioned, standard drainage control measures would ensure flood protection, and the unsaturated host rock should offer a benign ground-water environment. Tectonic processes could affect closure activities if the earthquake design limits that were imposed were not sufficiently conservative to guarantee the safety of the workers and retrieval of the waste, if necessary. Section 6.3.3.4.5 describes the procedure that will be used to develop conservative seismic design requirements for a repository at Yucca Mountain.

Cost Estimates

On the basis of the available site information and design studies completed to date, preliminary cost estimates have been developed for the repository described in Chapter 5. These estimates were developed as part of the U.S. Department of Energy annual evaluation of the adequacy of the one mil per kilowatt-hour fee for disposal services and do not represent final cost estimates. More definitive estimates will be completed when more detailed designs and site-characterization data become available.

The estimated total life-cycle cost for a repository located in tuff is \$8.5 billion (1984 dollars). This includes costs for development and evaluation (\$1.5 billion), construction (\$1.1 billion), operation (\$5.8 billion), and decommissioning (\$0.1 billion). The development and evaluation estimate includes costs for site characterization, repository conceptual design, and license application, and technology development. The construction estimate includes costs for repository final procurement and construction design and the construction of all surface facilities and a limited number of underground waste disposal rooms and corridors. The operations estimate includes costs for the construction of the remainder of the underground facilities, the emplacement of the waste underground, and caretaker and backfilling activities. The decommissioning estimate includes costs for shaft sealing and the decontamination and dismantling of the surface facilities.

6.3.4.1.4 Conclusions for the qualifying condition on the ease and cost of siting, construction, operation, and closure guideline

The siting, construction, operation, and closure of a repository at Yucca Mountain are not likely to require special technology and are considered feasible on the basis of existing technology. Site-characterization studies will expand the existing information on host-rock thickness and lateral extent, host-rock mechanical properties, thermo-mechanical properties, the location and characteristics of faults and shear zones, and the subsurface hydrologic system. The currently available repository design information, cost estimates, and design requirements will be updated during ongoing conceptual-design activities. The evidence collected and evaluated to date does not support a finding that the site is not likely to meet the qualifying condition of this preclosure system guideline (level 3).

6.3.5 CONCLUSION REGARDING SUITABILITY OF THE YUCCA MOUNTAIN SITE FOR SITE CHARACTERIZATION

On the basis of the findings stated in the previous discussion of individual guidelines and made in accordance with Appendix III of the siting guidelines (10 CFR 960, 1984), it is concluded that the evidence does not support a finding that the site is disqualified and does not support a finding that the site is not likely to meet the qualifying conditions for ease and cost of siting, construction, operation, and closure. Therefore, it is concluded that the Yucca Mountain site is suitable for site characterization.

6.4 PERFORMANCE ANALYSES

The preceding sections of Chapter 6 have presented guideline-by-guideline analyses of the suitability of the Yucca Mountain site for further

characterization. This section describes the preclosure and post-closure performance analyses that support the preclosure system guideline regarding radiological safety and the postclosure system guideline. Other assessments not related to preclosure radiological safety or postclosure performance are not considered here.

6.4.1 PRECLOSURE RADIOLOGICAL SAFETY ASSESSMENTS

The purpose of this section is to describe the approach to the preclosure radiological assessment, to determine whether the assessments are especially sensitive to particular characteristics of the site, and to estimate preclosure performance based on the existing information.

6.4.1.1 Preclosure radiation protection standards

The preclosure system guideline (10 CFR 960.5-1(a)(1), 1984) for radiological safety refers to meeting the applicable safety requirements set forth in 10 CFR Part 60 (1983), 40 CFR 191, Subpart A (1985), and 10 CFR Part 20 (1984). The Subpart A standard requires that the combined annual dose equivalent to any member of the public, from operations covered by 40 CFR Part 190 (1982) and from direct radiation and planned discharges of radioactive materials, not exceed 25 millirem to the whole body, 75 millirem to the thyroid, and 25 millirem to any other organ. The requirements of 10 CFR Part 20 establish limits to exposure of operating personnel, permissible concentrations of radionuclides in air and water for unrestricted areas, and offsite exposure of the general public. The last requirement is that the whole body dose to any member of the public in a year be less than 0.5 rem, with continuous dose limited to 2 millirem per hour or 100 millirem in any 7 consecutive days. This requirement is generally less restrictive than that of 40 CFR 191, Subpart A, but may be limiting under certain short-term conditions.

6.4.1.2 Methods for preclosure radiological assessment

The preclosure performance assessments will include evaluation of potential release and dose and comparison with the requirements of the regulations listed in Section 6.4.1.1. The assessments will consider repository construction and operations including both normal operating conditions and unexpected conditions (i.e., those involving accidental releases).

The specific analysis for each of these conditions will depend upon the designs of the facilities and the waste package. The main purposes of these analyses will be to confirm the acceptability of the designs and to identify mitigative measures to decrease consequences and preventive measures to preclude specific accidents. The analyses may depend on the characteristics of the site and, to the extent that the calculations are particularly sensitive to features of the site, these characteristics would need to be identified and evaluated with regard to preclosure system performance.

6.4.1.2.1 Radiological assessment of construction activities

No radioactive waste would be involved in the construction activities. However, radiation exposure could result from the release of radon from excavated rock and the underground facility. The amount of radon released to the environment depends upon site and engineered system characteristics, including:

1. The amount of natural uranium and thorium in the rock;
2. The characteristics of the rock (e.g., matrix density, porosity) that affect the rate of radon emanation from the rock;
3. The natural and induced thermal fields;
4. The volume and rock surface-area of underground openings;
5. The ventilation flow rate in underground openings, and
6. Other engineered features that are not defined at this stage of the design.

Neutron activation analyses performed on Topopah Spring tuff samples indicate natural uranium content to be in the range of 2.7 to 5.2 parts per million and natural thorium content to be in the range of 22.1 to 25.2 parts per million (Knauss, 1984; Ramspott, 1983). Using these results, the rock bulk density value of 2.12 grams per cubic centimeter (Tillerson and Nimick, 1984), and assuming secular equilibrium of the uranium and thorium series in the Topopah Spring tuff, it is estimated that the radon-220 (thorium series) production is approximately 6 picocuries per cubic centimeter and the radon-222 (uranium series) production is approximately 3 picocuries per cubic centimeters. The concomitant radon emanation rate from the rock, particularly as influenced by the induced thermal load from the emplaced radioactive waste, is not yet known. Although tentative dimensions and ventilation rates for underground openings have been determined, the radionuclide releases and radiation doses due to natural radon have yet to be evaluated.

For present purposes, estimates of radionuclide releases and radiation doses can be based upon data provided for various types of geologic media (DOE, 1980a). These estimates are discussed in Section 5.2.9.1.

These data indicate that excavation of rock roughly corresponding to the disposal of 70,000 metric tons of heavy metal of spent fuel would result in an annual effective whole-body dose for a member of the general population of less than 0.05 millirem. This estimate has been made for excavation of granite, the rock with the highest radon release per unit of excavated rock of those media evaluated in DOE (1980a); the estimate assumes that the release occurs at the point of the excavation. Specific characteristics of the site such as rock type or environmental conditions would not result in greater impacts, because the impact will be mitigated with design features, particularly features of the underground ventilation systems.

6.4.1.2.2 Radiological assessment of normal operations

Neither direct radiation sources nor radionuclide releases during normal operations constitute a significant source of public exposure because of the shielding, packaging, and containment measures that will be taken and because

of the large distance that separates the waste from the public. The shielding, packaging, and containment measures needed will be determined when the unit operations have been specified. The greatest potential for radionuclide release during normal operations would occur for the handling of the spent fuel assemblies. Upper bounds to potential impacts can be estimated for possible handling operations and assumptions regarding cladding failure.

A small fraction of the rods may experience cladding failure during reactor operation, or during residence in storage pools. In early designs the fraction of rods that failed during operation was almost 1 percent, but design modifications have reduced this fraction to less than 0.02 percent (Woodley, 1983). There is no evidence of transportation-related cladding failures (DOE, 1978). The fraction that would fail during temporary storage is unknown. If the cladding of any of the rods is ruptured during handling at the site, a portion of the radioactivity in the spent fuel could be released inside the hot cell. High-efficiency particulate air (HEPA) filtration systems can be assumed to remove virtually all (99.9+ percent) of the particulates released from the fuel. For conservatism, virtually all of the tritium, carbon-14, krypton-85 and iodine-129 should be assumed to pass through the system and to be released to the surrounding environment.

Under normal conditions, handling could only result in cladding failure if disassembly of spent fuel elements is performed. For example, up to 0.3 percent of the rods could become stuck in the rod spacers because of swelling in the reactor core (Funk and Jacobson, 1979), and some fraction of these could be ruptured during removal from the spacer with an associated release of the fractions stated above for tritium, carbon-14, krypton-85 and iodine-129.

An estimate of the radionuclide emissions during normal operations can be made from the expected arrival rate of spent fuel rods, frequency of rod failure, radionuclide inventory of the failed rods, and fraction of this inventory that could be released. An upper bound to the release is calculated by assuming an arrival rate of 3,000 metric tons of heavy metal of spent fuel (corresponding to 1,700,000 fuel rods for pressurized-water-reactor fuel) each year, by assuming 0.3 percent of the pins have ruptured and will be stuck in the spacers during disassembly, and by assuming that all of the stuck rods will be ruptured during removal from the spacers. The resulting release fractions are given in Table 6-46. Air concentrations are calculated on the basis of a dispersion factor (X/Q) estimated to be 2×10^{-5} seconds per cubic meter (6×10^{-7} seconds per cubic foot). The calculated concentrations are compared with the concentration limits set by 10 CFR Part 20 (1984) in Table 6-46. Potential exposure can be mitigated by specific facility designs.

Evaluation of committed dose equivalent to compare with regulatory standards will require site-specific information, such as exposure pathway data. However, bounding estimates can be made for simple cases; for example, when the radioactive gases are dispersed in the atmosphere, the whole-body dose equivalent for immersion in the dispersed cloud can be estimated by using site-independent dose factors (ICRP, 1979). For the release in Table 6-46 and a dose conversion factor for krypton-85 of 2×10^4 (rem per year) per (curies per cubic meter) (ICRP, 1979), the calculated dose equivalent is less than 0.2 millirem per year.

Table 6-46. Assessment of releases from normal preclosure operations

Radionuclide	Inventory ^a (curies)	Fraction released per year ^b	Calculated concentration in air ^c (Ci/m ³) ^d	Concentration limit ^e (Ci/m ³)
Hydrogen-3	9.3×10^5	0.0003	1.8×10^{-10}	2×10^{-7}
Carbon-14	3.7×10^3	0.0003	7.0×10^{-13}	1×10^{-7}
Krypton-85	1.5×10^7	0.0009	8.6×10^{-9}	3×10^{-7}
Iodine-129	9.3×10^1	0.0003	1.8×10^{-14}	2×10^{-11}

^aBased on 3,000 metric tons of heavy metal of 10-year-old spent fuel arriving in a year (DOE, 1979).

^bBased on 0.3 percent failure of spent fuel rods and fraction of radioactive gases from failed rods released from facility. Regulatory Guide 1.25 (NRC, 1972) indicates that fractions would be 30 percent for krypton-85 and 10 percent for iodine-129. Tritium and carbon-14 are also assumed to be 10 percent.

^cBased on $X/Q = 2 \times 10^{-5}$ seconds per cubic meter.

^dCi/m³ = curies per cubic meter.

^eConcentration limits in 10 CFR 20, Appendix B (1984).

6.4.1.2.3 Radiological assessment of accidental releases

The estimates of releases will depend upon the accidents that are plausible at the site. The possible set of accidents to be considered may be altered for specific facility design and operational techniques. A broad spectrum of potential accidents was analyzed by DOE (1979). The most severe of these involved hoist failure during the lowering of the waste disposal container to the repository level. As described in Section 5.1.1.2, however, the reference access method for transferring waste to the underground facility of the prospective Yucca Mountain repository is via a ramp entry. Therefore, the waste-hoist failure would not be a possible event.

As described in Section 5.2.9.2.3, preliminary safety analyses (Jackson et al., 1984) indicate that worst-case accident consequences result from an aircraft impact. For this event, the calculated whole-body equivalent dose to the maximally exposed individual is 68 millirem.

6.4.2 PRELIMINARY ANALYSIS OF POSTCLOSURE PERFORMANCE

This section presents a preliminary performance analysis for the proposed Yucca Mountain waste disposal system. The objective of this preliminary analysis is to estimate the likelihood of satisfying the regulatory requirements contained in the Nuclear Regulatory Commission (NRC) regulations in

10 CFR Part 60 (1983) and the U.S. Environmental Protection Agency (EPA) regulations in 40 CFR Part 191 (1985). The results of the analysis are used in Section 6.3.2 in evaluating the site against the postclosure system guideline (10 CFR 960.4-1, 1984), which is based on these NRC and EPA regulations.

Because of limitations in the data base and analytical methods, this preliminary analysis is not intended to demonstrate compliance with the postclosure performance objectives; rather, it is intended to supplement the evidence that will be used to establish whether the Yucca Mountain site is suitable for site characterization. A full performance assessment to demonstrate compliance with the postclosure performance objective is contingent on site characterization and will follow it.

This section is divided into five parts. Section 6.4.2.1 describes the two major subsystems of the proposed Yucca Mountain waste disposal system. The first of these, the engineered barrier subsystem, is evaluated by an assessment of waste package performance; the second, the natural barrier subsystem, is evaluated at this time by evaluations of ground-water flow and geochemical retardation. The individual performance of each subsystem is analyzed in Section 6.4.2.2, and a preliminary analysis of total system performance is presented in Section 6.4.2.3. Section 6.4.2.4 compares the subsystem and total system performance discussed in earlier sections with the applicable requirements of 10 CFR Part 60 (1983) and 40 CFR Part 191 (1985). The objective of these comparisons is to establish a rough measure of system performance under the conditions expected in the repository; a brief discussion of the effects of disruptive events on system performance is provided in Section 6.4.2.5.

6.4.2.1 Subsystem descriptions

For the purpose of these assessments, it is assumed that a repository at Yucca Mountain would be constructed in the primary area of investigation (Section 6.3.3.2) of roughly 890 hectares (2,200 acres). The underground working areas would be 200 meters (656 feet) or more below the surface in the lower portion of the densely welded Topopah Spring Member (Figure 6-25) of the Paintbrush Tuff. The present repository concept specifies that 616 hectares (1,520 acres) are required for the repository, and mined areas will occupy no more than 25 percent of the total area. It is assumed that the waste will be emplaced as 10-year-old spent fuel and will reach a total of 70,000 metric tons of heavy metal (MTHM) at closure. The radionuclide inventory is given in Table 6-47.

The quantities of radioactive waste and the associated radionuclide inventories that would actually be emplaced in the repository have not yet been established, and the amount of spent fuel emplaced could be less than 70,000 MTHM. Other wastes may be emplaced in the repository in addition to the spent fuel. These other wastes may include high-level wastes currently in storage at West Valley, New York, and defense waste processing facility high-level waste.

These wastes have been explicitly factored into the transportation analyses in Section 5.3. However, the curie inventories of these wastes

Table 6-47. Radionuclide inventory in repository at 360 and 1,060 years after emplacement of 10-year-old spent fuel

Radionuclide	Half-life (years)	Specific activity (Ci/g) ^a	Radionuclide inventory (Ci/1000 MTU) ^a		
			t = 10 yr ^b	t = 360yr ^c	t = 1,060 yr ^c
Cm-246	5.5 x 10 ³	2.64 x 10 ⁻¹	3.5 x 10 ¹	3.4 x 10 ¹	3.1 x 10 ¹
Cm-245	9.3 x 10 ³	1.57 x 10 ⁻¹	1.8 x 10 ²	1.8 x 10 ²	1.7 x 10 ²
Cm-244	1.76 x 10 ⁻¹	8.32 x 10 ¹	9.0 x 10 ⁵	9.3 x 10 ⁻¹	0
Cm-242	4.5 x 10 ⁻¹	3.32 x 10 ³	8.5 x 10 ³	2.6 x 10 ³	1.1 x 10 ²
Am-243	7.95 x 10 ³	1.85 x 10 ⁻¹	1.4 x 10 ⁴	1.4 x 10 ³	1.3 x 10 ²
Am-242	1.52 x 10 ²	9.72	1.0 x 10 ⁴	2.6 x 10 ⁶	1.1 x 10 ⁵
Am-241	4.58 x 10 ⁵	3.24	1.6 x 10 ⁶	1.0 x 10 ³	3.5 x 10 ³
Pu-242	3.79 x 10 ¹	3.90 x 10 ⁻³	1.6 x 10 ³	1.6 x 10 ²	1.6 x 10 ²
Pu-241	1.32 x 10 ³	1.12 x 10 ²	6.9 x 10 ⁷	1.8 x 10 ⁵	1.7 x 10 ⁵
Pu-240	6.58 x 10 ³	2.26 x 10 ⁻¹	4.5 x 10 ⁵	4.4 x 10 ⁵	4.1 x 10 ⁵
Pu-239	2.44 x 10 ⁴	6.13 x 10 ⁻²	2.9 x 10 ⁵	2.9 x 10 ⁵	2.8 x 10 ²
Pu-238	8.6 x 10 ¹	1.75 x 10 ¹	2.0 x 10 ⁶	2.0 x 10 ⁴	9.3 x 10 ⁴
Np-239	6.4 x 10 ⁻³	2.33 x 10 ⁵	1.4 x 10 ⁴	1.4 x 10 ²	1.3 x 10 ²
Np-237	2.14 x 10 ⁶	7.05 x 10 ⁻⁴	3.1 x 10 ²	4.4 x 10 ²	5.8 x 10 ²
U-238	4.51 x 10 ⁹	3.33 x 10 ⁻⁷	3.2 x 10 ²	3.2 x 10 ²	3.2 x 10 ²
U-236	2.39 x 10 ⁷	6.34 x 10 ⁻⁵	2.2 x 10 ²	2.2 x 10 ²	2.3 x 10 ²
U-235	7.1 x 10 ⁸	2.14 x 10 ⁻⁶	1.6 x 10 ¹	1.6 x 10 ¹	1.6 x 10 ¹
U-234	2.47 x 10 ⁵	6.18 x 10 ⁻³	7.4 x 10 ¹	7.2 x 10 ²	7.8 x 10 ²
U-233	1.62 x 10 ⁴	9.47 x 10 ⁻²	3.8 x 10 ⁻²	5.3 x 10 ⁻¹	2.1
Pa-231	3.25 x 10 ¹⁰	4.51 x 10 ⁻⁷	5.3 x 10 ⁻⁷	1.3 x 10 ⁻⁶	3.7 x 10 ⁻⁵
Th-232	1.4 x 10 ⁴	1.10 x 10 ⁻²	1.1 x 10 ⁻³	4.1 x 10 ⁻⁶	1.2 x 10 ⁻⁵
Th-230	8.0 x 10 ³	1.94 x 10 ⁻²	4.1 x 10 ⁻³	2.2	9.0
Th-229	7.34 x 10 ³	2.13 x 10 ⁻¹	2.8 x 10 ⁻⁵	8.0 x 10 ⁻³	9.2 x 10 ⁻²
Ra-226	1.60 x 10 ⁻²	9.88 x 10 ⁴	7.4 x 10 ⁻⁶	1.2 x 10 ⁻³	1.5
Ra-225	4.05 x 10 ¹	3.92 x 10 ¹	8.1 x 10 ⁻⁵	8.1 x 10 ⁻¹	9.4 x 10 ⁻²
Pb-210	2.23 x 10 ¹	7.63 x 10 ¹	7.0 x 10 ⁻⁷	1.5 x 10 ⁻¹	1.7
Cs-137	3.0 x 10 ⁶	8.70 x 10 ⁻⁴	7.5 x 10 ²	2.3 x 10 ²	2.2 x 10 ⁻³
Cs-135	3.0 x 10 ⁷	8.82 x 10 ⁻⁴	2.7 x 10 ¹	2.7 x 10 ¹	2.7 x 10 ¹
I-129	1.59 x 10 ⁵	1.74 x 10 ⁻²	3.3 x 10 ²	3.3 x 10 ²	3.3 x 10 ²
Sn-126	1.0 x 10 ⁵	2.84 x 10 ⁻²	4.8 x 10 ⁴	4.8 x 10 ⁴	4.8 x 10 ⁴
Tc-99	2.15 x 10 ⁵	1.70 x 10 ⁻³	1.3 x 10 ³	1.3 x 10 ³	1.3 x 10 ³
Zr-93	9.5 x 10 ¹	4.04 x 10 ²	1.7 x 10 ⁷	1.7 x 10 ⁴	1.7 x 10 ⁻⁴
Sr-90	2.9 x 10 ⁴	1.37 x 10 ⁻²	5.2 x 10 ¹	1.2 x 10 ¹	6.5 x 10 ¹
Ni-59	8.0 x 10 ³	7.57 x 10 ⁻²	3.0 x 10 ²	3.0 x 10 ²	3.0 x 10 ²
C-14	5.73 x 10 ³	4.45	8.0 x 10 ²	7.4 x 10 ²	6.9 x 10 ²

^a MTU = metric tons of uranium; Ci/g = curies per gram.

^b 10 years out of reactor, i.e., the assumed time of emplacement; values taken from tables 3.3.7, 3.3.8, and 3.3.10 of DOE, 1979; once-through-reactor cycle.

^c 300 or 1,000 years after closure, i.e., 360 or 1,060 years out of reactor, assuming a 50-year operations period before closure; values calculated from 10-year inventories and rounded to 2 significant digits.

would constitute less than 1 percent of total repository inventory and would not have a significant incremental impact on repository performance. Therefore, these other wastes are not explicitly evaluated here.

The waste disposal system consists of three major components: (1) the waste package; (2) the mined repository, including any engineered features that are specifically intended to enhance long-term waste containment or isolation; and (3) the geohydrologic and geochemical setting of the site. These three components are described below in terms of their subcomponents that are relevant to postclosure performance.

6.4.2.1.1 Engineered barrier subsystem

The waste package

A reference conceptual design (O'Neal et al., 1984) for a spent fuel waste package is shown in Figure 6-28. The waste disposal container is 70 centimeters (28 inches) in diameter, but its length, including the pintle, may vary from 4.0 to 4.75 meters (13 to 15.6 feet) to accommodate various lengths of fuel rods. The container is fabricated from austenitic stainless steel with a wall thickness of 1 centimeter (0.4 inch). This design will accommodate the fuel rods from 7 pressurized-water-reactor assemblies (3.30 kilowatts) or 14 boiling-water-reactor assemblies (2.66 kilowatts); the fuel rods would be removed from the original assembly hardware and consolidated to fit in the waste disposal containers. The power loadings of 3.30 and 2.66 kilowatts are consistent with a 350°C (662°F) temperature limit imposed to avoid degradation of the Zircaloy cladding around the spent fuel (O'Neal et al., 1984). If it is assumed that the initial thermal loading of the repository is held to 119 kilowatts per hectare (48 kilowatts per acre), then about 18,000 containers would be distributed over 510 hectares (1,260 acres).

The design shown in Figure 6-28 is the least complicated of the selected reference and alternative design configurations for this spent fuel waste package (O'Neal et al., 1984). The waste disposal container would be emplaced in a single vertical borehole, and neither an overpack nor packing material would be used.

Austenitic stainless steel has been chosen as the reference material because of its excellent corrosion and oxidation resistance in environments similar to those anticipated in the Yucca Mountain repository during the containment period. The corrosion and oxidation behavior of one austenitic stainless steel, AISI 304L, has been extensively studied. Test results to date indicate that either uniform corrosion or stress corrosion cracking is the expected failure mode for this material in the dominant environmental conditions in the Yucca Mountain repository. More highly alloyed grades of austenitic stainless steels (AISI 316L and 321) and the related high-nickel austenitic alloy (825) are also being tested as candidate container materials; these alloys are very resistant to localized and stress-assisted forms of corrosion (pitting, crevice, intergranular, stress corrosion cracking, hydrogen embrittlement). Any of these austenitic materials can be used for fabricating the disposal containers illustrated in Figure 6-28. The

Figure 6-28. Reference conceptual design for spent fuel waste disposal container. From O'Neal et al. (1984).

effects of different fabrication and welding processes on the corrosion and oxidation performance of the container materials are being studied. So far, tests in the expected Yucca Mountain environments have shown no evidence of localized or stress-assisted corrosion. Tests to qualify the candidate container materials are continuing, but because such tests have not demonstrated any failure of 304L by stress corrosion cracking, even under extreme cold-worked, sensitized, and highly stressed conditions, the modeling of containment-barrier lifetime will be based on uniform corrosion, which is known to occur at measureable rates. However, the role of stress corrosion cracking remains a subject of further study.

Copper and copper-base alloys serve as an alternative alloy system to the austenitic materials. Expected corrosion degradation mechanisms and the environmental conditions that cause them are different on copper from those on stainless steel. Alloying additions improve the resistance of copper to corrosion in the expected oxidizing environments. High-purity copper (CDA 102), aluminum bronze (CDA 613), and 70/30 copper-nickel (CDA 715) are being tested. Some modification to the present reference and alternative waste package designs may be needed for copper containers.

The mined repository

By the Nuclear Regulatory Commission (NRC) definition, the engineered barrier consists of the waste package and the underground facility of the repository. These two components combine to provide long-term containment and to control the release of the radioactive material into the geologic setting.

The outer boundary of the mined repository has not yet been clearly defined. The NRC states in 10 CFR Part 60 (1983) that the repository includes the underground structure, underground openings, and backfill materials but excludes shafts, exploratory boreholes, and their seals. For the current calculations, the boundary of the engineered barrier subsystem is defined as a surface coinciding with the walls of the waste-emplacement drifts and emplacement holes.

At present, preliminary hydrologic information and preliminary design data are available to predict the effects of the engineered barrier subsystem on water availability at the waste disposal container. While estimates of the retardation that occurs inside the boundary of the engineered barrier subsystem could be made, the release rate at the accessible environment would not be significantly affected because the major sorptive unit is the tuffaceous beds of Calico Hills, which is some distance below the repository horizon. In future performance analyses, the host rock immediately surrounding the waste disposal containers could be treated either as part of the engineered barrier or the natural barrier subsystem.

6.4.2.1.2 The natural barrier subsystem (the geohydrologic setting)

This preliminary analysis is directed at two components of the natural barrier subsystem: ground-water and geochemical conditions. The most important aspects of these components are (1) the volume and flow of water in the

saturated and the unsaturated zones of Yucca Mountain and (2) the geochemical properties of the rocks and waters of Yucca Mountain as they relate to the potential solution, suspension, complexing, and transport of radionuclides by the ground water.

The available information on the flow of water in the saturated and the unsaturated zones of Yucca Mountain is reviewed in Section 6.3.1.1. Briefly, the flow of water occurs in a thick unsaturated section (about 500 to 750 meters, or 1,640 to 2,460 feet thick) and a deep saturated zone. The host rock for the repository is in the unsaturated zone and is characterized by low water content; the repository horizon is generally over 200 meters (656 feet) above the water table.

Water enters the unsaturated zone in the form of precipitation that infiltrates at the land surface and percolates generally vertically downward until it reaches the water table. The flow rate of the percolating water is determined by the rate of infiltration and by the hydraulic properties of the rocks in the unsaturated zone as described in Section 6.3.1.1. On reaching the water table, the ground water then moves in a generally horizontal direction to the accessible environment. It is driven by a hydraulic gradient approximately equal to the slope of the water table and is controlled by the hydraulic properties of the intervening rocks. It is probable that a portion of the ground-water flow in the saturated zone at Yucca Mountain occurs through fractures in the welded units.

The available information on the geochemical properties of the Yucca Mountain site is reviewed in Section 6.3.1.2. Between the repository horizon and the water table, there are several zones containing highly sorptive minerals, particularly zeolites and clays. The formations in the saturated zone also contain varying amounts of clays and zeolites. Because of the sorptive properties of these rocks, dissolved radionuclide-bearing compounds may be transported at effective speeds that are generally less than the local pore-water velocity; this is particularly true if flows are confined to the matrix of the rocks. The reduced speed results in a transport time over the same flow path that is longer than the water-flow time by a number known as the retardation factor, R_f (Equation 6-2). The retardation factor for the j th radionuclide species, $R_f(j)$, is related to the distribution coefficient for the j th species, $K_d(j)$, by the expression (Freeze and Cherry, 1979)

$$R_f(j) = 1 + \frac{\text{bulk density} \times K_d(j)}{\text{porosity}}. \quad (6-4)$$

Estimates of distribution coefficients (also known as the sorption ratios, R_d) and retardation factors are listed in Table 6-25 for several waste elements in six of the tuff units that could be crossed by flow in the unsaturated and the saturated zones. These estimates are based on retardation by sorption. Other chemical and physical retardation mechanisms, such as precipitation and matrix diffusion, may increase the effective retardation factor, especially for elements with low sorption ratios. The waste elements with low or zero sorption ratios, hence small retardation factors, are carbon, iodine, and technetium. These few elements will be transported with a speed nearly equal to that of the ground water, unless they are slowed by

physical retardation mechanisms or nonsorptive chemical retardation. This possibility is currently under investigation.

6.4.2.2 Preliminary performance analyses of the major components of the system

The performance of each of the three major components of the waste disposal system is evaluated here. The results will be used in Section 6.4.2.3 to establish a reference system configuration and in Section 6.4.2.4 to make comparisons with regulatory performance objectives.

In the remainder of this section, and unless otherwise stated, the use of the term accessible environment is consistent with 40 CFR Part 191 (1985) and means those parts of the lithosphere and atmosphere that lie at a maximum distance of 5 kilometers (3 miles) in any direction from the original location of the radioactive waste.

6.4.2.2.1 The waste package lifetime

For the waste package, the Nuclear Regulatory Commission has provided a performance objective that calls for substantially complete containment of radioactive wastes for 300 to 1,000 years. For purposes of the present analyses, the containment period of the waste package is assumed to be the time during which the waste disposal container is impervious to liquid water. There is, of course, a period of time during which temperatures within and in the vicinity of the containers exceed the boiling point of water, and no liquid water would contact the waste regardless of the integrity of the container; that period of time is not counted in the present analyses. Rather, the lifetime of the reference container is assessed in terms of its resistance to uniform corrosion, the expected failure mode of austenitic stainless steel (see discussion of the waste package in Section 6.4.2.1). Estimates of the uniform corrosion rate for this and other materials have been made based on data from short-term exposure tests that attempt to simulate the Yucca Mountain environment. In addition, there are considerable data in the literature concerning the corrosion properties of 304L stainless steel.

In low-salinity, aerated water with a nearly neutral pH, the uniform-corrosion rate for 304L stainless steel appears to be less than 0.1 mil per year, or about 2.5×10^{-4} centimeter (1.0×10^{-4} inch) per year (Paul and Moran, 1963). If uniform corrosion is the only mechanism that acts to breach the waste disposal container, its lifetime will be about 3,000 years. In contrast to these results, McCright et al. (1983) have observed a maximum rate of 3.7×10^{-5} centimeter (1.5×10^{-5} inch) per year for the uniform corrosion of 304L stainless steel in 2-month exposure tests. In their tests, the sample was immersed under pressure at a temperature of 105°C (221°F) in water from a well in the vicinity of Yucca Mountain (Well J-13) and simultaneously was subjected to a radiation field of 3×10^5 rads per hour. The container lifetime under these conditions would be about 30,000 years. However, McCright et al. (1983) conclude that a conservative upper limit of

1×10^{-4} centimeter (4×10^{-5} inch) per year is reasonable for the uniform corrosion of 304L stainless steel in the Yucca Mountain environment and that the expected container lifetimes are accordingly on the order of 10,000 years.

In summary, the containment period of the waste package could range from 3,000 to 30,000 years if waste disposal container failure through mechanisms other than uniform corrosion can be confidently excluded from consideration. Since sufficient data on the vulnerability of candidate container alloys to failure mechanisms other than uniform corrosion are not yet available, the lower bound on the range of waste package lifetimes, 3,000 years, will be adopted for the analysis of the reference case in Section 6.4.2.3 to achieve some degree of conservatism.

6.4.2.2.2 Release rate from the engineered barrier subsystem

As stated in Section 6.4.2.1, the elements of the repository that would make up the engineered barrier subsystem at the Yucca Mountain site are not yet rigorously defined. To facilitate the present assessments, the inner boundaries of this subsystem are assumed to coincide with the outer boundaries of the waste packages, and the rate of radionuclide release from the engineered barrier subsystem is calculated as the rate of mass transport across the geometrical envelope containing the waste packages.

As long as the uncorroded thickness of the waste disposal container walls was at least a few microns, there could be no significant mass transfer from the interior of the container to its exterior; hence there would be little or no release of nonvolatile, radionuclide-bearing compounds. But, at some time (3,000 to 30,000 years), corrosion or other mechanisms will have attacked the container walls long enough to have produced openings of sufficient size to permit the free passage of water between the interior and exterior; water could then contact the spent fuel rods inside the container. The amount of water that could flow into the container is limited, however. Given the assumed prevailing, downward flux in the rock surrounding the waste emplacement borehole, the discharge of water into the container (and, in steady flow, out of the container) could be no more than FA (in cubic meters per year), where F is the flux (in meters per year) and A is the container area normal to the flux (in square meters). Thus, for an expected flux of less than 0.5 millimeter (0.02 inch) per year ($F = 10^{-3}$ meters per year) and a vertically emplaced reference container ($A = 0.33$ square meter), no more than 0.17 liter (0.04 gallon) of water per year could enter (and exit) the waste disposal container.

Any water that penetrates the waste disposal container could contact the Zircaloy-clad fuel rods. The Zircaloy cladding could offer further protection of the bare spent fuel, but the amount of protection is uncertain, particularly over the long term. Woodley (1983) examined the characteristics of spent fuel from light-water reactors and estimated the cladding failure rate for boiling-water-reactor fuel designs to be between 1.0 percent and a value approaching zero. The lower bound for cladding failures will probably remain near 0.01 to 0.02 percent (Locke, 1975; Garzarolli et al., 1979). In any case, spent fuel cladding will not be 100 percent intact at emplacement.

In the present assessments, any protection offered by the cladding will be ignored. Thus, it is assumed that any water penetrating the container will always contact the bare waste form contained within the Zircaloy cladding, leading to some dissolution of the waste and mass transfer from the waste form to the liquid phase in the form of soluble compounds containing radionuclides.

According to available data, the possible mass-transfer rates from spent fuel to water could vary from essentially zero (for intact Zircaloy-clad fuel rods) to more than 1 part in 100,000 per year for bare fuel elements. The latter rates are, however, extremely unlikely under Yucca Mountain conditions. Wilson and Oversby (1984) report the initial results from tests of spent fuel cladding containment. Solution concentrations indicate a uranium-release rate of 5×10^{-6} per year from bare fuel (pellets from a 13-centimeter (5-inch) long rod segment) submerged in 250 milliliters (6.6×10^{-2} gallon) of deionized water and a release rate of 2×10^{-5} per year for plutonium. These results are similar to release rates measured by Stroes-Gascoyne et al. (1985) in a study of the long-term dissolution of spent fuel in distilled water at 25°C (77°F). Similar studies by Wilson and Oversby (1984) suggest that release rates from spent fuel samples with relatively large artificially induced cladding defects are still 10 to 100 times lower than the release rates from bare fuel. These mass-transfer rates are high enough to suggest that, under the low-flux conditions of Yucca Mountain where water could remain in contact with the waste form for relatively long times, use of a saturation-limited dissolution model is justified. In fact, under saturated conditions in release-rate experiments (Wilson and Oversby, 1984), with high ratios of water volume to waste-form area, solution concentrations appear to reach a steady state in less than 30 days. For the large flux values that would be typical of fracture flow (considered unlikely at Yucca Mountain), solubility kinetics may control the release rate, and a saturation-limited dissolution model would overestimate the rates. Another control on the release rate is the rate at which dissolved compounds at the waste-water interface can diffuse into the flowing water (see Section 6.3.1.2, favorable condition 4). In saturation-limited dissolution, neither kinetics nor diffusion are accounted for, and each unit volume of water that contacts a soluble compound is assumed to attain a solution concentration of that compound no less than S kilograms per cubic meter, where S is the solubility (or solubility limit) of the compound in the solvent under consideration and is a quantity depending on many environmental variables (e.g., temperature, pressure, concentrations of other solute compounds).

The foregoing considerations suggest a way of using the saturation-limited dissolution model to estimate the rate of mass transport across the engineered barrier system. Taking a single waste disposal container (described in Section 6.4.2.1) as the unit of inventory, the rate of mass loss from the engineered barrier owing to dissolution of the spent fuel matrix, $\dot{M}$, should be no more than the expression, $\dot{M} = FAS$, where, to reiterate, F is the flux of water (in cubic meters per square meter per year), A is the container area normal to the flux (in square meters), and S is the solubility limit of the waste matrix (in kilograms per cubic meter). If the upper bound on flux is 0.5 millimeter per year (5×10^{-4} meter per year), $A = 0.33$ square meter (a vertically emplaced reference container), and $S = 5 \times 10^{-2}$ kilogram per cubic meter, an upper limit on the solubility of

uranium dioxide in waters characteristic of Yucca Mountain (Ogard and Kerrisk, 1984), the rate of mass loss is 8.3×10^{-6} kilogram per year. For a container that is assumed to hold 3.3 metric tons of heavy metal, the fractional mass release rate is 2.5×10^{-9} per year. The rate of mass loss in the form of a radionuclide-bearing compound may also be estimated in the same way if S, the solubility limit of the waste matrix, is replaced with the smaller of the two quantities, solubility limit of waste matrix and solubility limit of the radionuclide-bearing compound, and the resulting fractional mass release rate is multiplied by the mass of the radionuclide remaining in the waste disposal container. For those radionuclide species having solubility limits greater than the solubility of the waste matrix, the fractional release rate is seen to be the same as the fractional mass release rate that applies to the total inventory of the container. The solubilities of several waste elements are listed in Table 6-26. With the exception of carbon, cesium, technetium, and iodine (not shown), all solubility values are less than or comparable to the value for uranium oxide.

Flux-dependent rates of mass loss of the type just described will be adopted for the analyses in Section 6.4.2.3; but they are not suitable for making conservative estimates of fractional release rates for purposes of comparing with the Nuclear Regulatory Commission objective for radionuclide releases from the engineered barrier system (generally, no more than one part in 100,000 per year). The rate-of-mass-loss formulation described above does not include mass loss of those solid phases that are not contained in the spent fuel matrix. Oversby and McCright (1984) have described the likely locations and amounts of radionuclides that reside outside of the bare, spent fuel pellet. They postulate that four components of the inventory should be considered in calculating release rates:

1. Radionuclides with releases controlled by matrix dissolution.
2. Radionuclides present in part in the pellet-cladding gap.
3. Radionuclides present in steel spacers and grids.
4. Radionuclides contained in the fuel cladding.

The saturation-limited dissolution models account for component (1), the overwhelming majority of the inventory. The radionuclides of component (2) (cesium, iodine, and possibly technetium) usually amount to less than 1 percent of their total inventory. The high leach rate for cesium-137 observed by Stroes-Gascoyne et al. (1985) in sections of bare spent fuel is probably a consequence of the segregation of a small fraction of the cesium inventory in component (2). In any case, the small fraction of the inventory residing in component (2) can be ignored in calculations of the long-term release at the accessible environment. The most significant radionuclide present in components (3) and (4) is probably the carbon-14 contained in the cladding. In the present analyses, all carbon-14 is assumed to be imbedded in the spent fuel matrix.

Ground-water travel times

Estimates of ground-water travel time from the repository to the accessible environment will be needed for the analyses in Section 6.4.2.3. These

estimates are directly taken from the arguments in Section 6.3.1.1.5 that use various lines of reasoning and evidence to show that (1) 0.5 millimeter (0.02 inch) per year is a reasonable and conservative upper bound on flux to use in calculating unsaturated zone, pre-waste-emplacement travel time; (2) flux below the repository horizon can be regarded as vertical and faults are not known to be continuous pathways from the repository to the water table; and (3) travel times between a point 50 meters (160 feet) below the centerline of the repository and the water table take on a distribution of values (at 0.5 millimeter (0.02 inch) per year, the mean travel time is 43,405 years with a standard deviation of 12,800 years). The travel times through the saturated zone to the accessible environment 5 kilometers (3 miles) from the margin of the repository were also estimated in Section 6.3.1.1.5 but will not be taken into account in the calculations of Section 6.4.2.3.

As explained in Section 6.3.1.1.5, a distribution of ground-water travel times is obtained when one takes into account the variable thicknesses of the rock units and the natural variability of hydraulic properties (e.g., effective porosity, saturated matrix conductivity) within each unit. The distribution of ground-water travel times may also be interpreted as the probability that a nonretarded contaminant particle, which is released at a randomly selected point in the repository, will reach the accessible environment in a specified time interval following release. The use of such distributions of ground-water travel times in the calculations of the release of nonretarded, radionuclide-bearing compounds in Section 6.4.2.3. improves the realism of such calculations, since part of the effects of hydrodynamic dispersion can be included (Freeze and Cherry, 1979).

Reference retardation factors

Point estimates of porous-flow retardation factors in the welded and the nonwelded tuff units will also be needed for the analyses in Section 6.4.2.3. These estimates are shown in Table 6-48; they are consistent with the geochemical properties of the tuffs at Yucca Mountain described in Section 6.3.1.2, although the estimates of retardation factors were based on different rock densities and hydrologic parameters. To be consistent with the theory of flow in partially saturated porous media, moisture contents were used in the formula for R_f given in Section 6.4.2.1.2 in place of porosity to generate the estimates of the retardation factors in Table 6-48. Also, bulk densities of 2.33 and 1.48 grams per cubic centimeter were assigned to welded and nonwelded tuff, respectively based on Scott et al. (1983); these values of bulk density are different from the value (2.5 grams per cubic centimeter) assumed in Table 6-25. A comparison of the two tables, 6-48 and 6-25, shows that the resulting differences in retardation factors are not large and, as will be demonstrated in Section 6.4.2.3, are not essential to the present analysis. The largest source of uncertainty in the retardation factor is the distribution coefficient, which may vary by factors of 10 or even 100 (Daniels et al., 1982), though it is unlikely that the spatially averaged distribution coefficients could be overestimated by factors of 100. The estimates given in Table 6-25 are believed to represent spatial averages.

A study of Table 6-48 reveals that all important radionuclide-bearing compounds, except those containing carbon, iodine, or technetium, have

Table 6-48. Distribution coefficients (sorption ratios) and calculated retardation factors used in preliminary system performance analyses--reference case

Element	Distribution coefficient, ^a K_d (ml/g)		Retardation factor, ^b $R_f(j)$	
	Welded	Nonwelded	Welded	Nonwelded
Americium (Am)	1,200	4,600	28,000	24,000
Carbon (C)	0 ^c	0 ^c	1	1
Curium (Cm)	1,200	4,600	28,000	24,000
Cesium (Cs)	290	7,800	6,700	41,000
Iodine (I)	0 ^c	0 ^c	1	1
Neptunium (Np)	7	11	160	58
Protactinium (Pa)	64	140	1,500	740
Lead (Pb)	5 ^d	5 ^d	120	27
Plutonium (Pu)	64	140	1,500	740
Radium (Ra)	25,000 ^e	25,000 ^e	580,000	130,000
Tin (Sn)	100 ^d	100 ^d	2,300	530
Strontium (Sr)	53	3,900	1,200	21,000
Technetium (Tc)	0.3	0 ^c	8	1
Thorium (Th)	500 ^d	500 ^d	12,000	2,600
Uranium (U)	1.8	5.3	27	45
Zirconium (Zr)	500 ^d	500 ^d	12,000	2,600

^aUnless otherwise indicated, distribution coefficients (sorption ratios) were taken from Table 6-25 or were inferred from the sorption ratios quoted by Daniels et al. (1982); ml/g = milliliters per gram.

^bCalculated using values of moisture content of 10 and 28 percent and bulk densities of 2.33 and 1.48 grams per cubic centimeter for welded and nonwelded tuff.

^cNo data available; assumed to be zero.

^dInferred from the mid-range retardation factor for tuffs in compilation in Table 7-1 in National Research Council (1983).

^eBarium used as a chemical analog.

retardation factors greater than 10. Consequently, carbon, iodine, and technetium can be reasonably assumed to have transport-time distributions identical with the water travel-time distributions described in Section 6.3.1.1.5, whereas the transport-time distributions for the dissolved compounds bearing the other radionuclides species are expected to be the water travel-time distribution uniformly shifted to larger times by a factor approximately equal to the average retardation factor for the combination of rock units crossed by the flow. The latter expectation has been tested for uranium using the retardation factors shown in Table 6-48 and the numerical simulation of ground-water travel described in Section 6.3.1.1.5; the sample mean of the transport-time distribution for uranium was 452,303 years, and the standard deviation was 77,115 years. This result suggests that cumulative releases of uranium (and also any radionuclide with a retardation factor greater than that for uranium) would be miniscule, even over a 100,000-year period, and that all species except carbon, iodine, and technetium can be ignored in the calculations of release to the accessible environment that will be presented in the following section.

6.4.2.3 Preliminary system performance analysis

The purpose of this section is to provide information for the preliminary evaluation of the Yucca Mountain site against the postclosure system guideline (Section 6.3.2). The purpose is accomplished by using simple methods, available information, and the results of the preliminary subsystem performance analyses in Section 6.4.2.2 to estimate the performance of the total system. The measure of total system performance will be given by the cumulative curies released to the accessible environment in the form of the j th radionuclide up to time t after repository closure. Times beyond 100,000 years after closure are not considered in these analyses.

6.4.2.3.1 System description

A simple conceptual model of the proposed waste disposal system at Yucca Mountain is shown in Figure 6-29. The level of detail in this conceptual model is consistent with the present knowledge of the natural and the engineered barrier subsystems, as well as the information available on the components of the waste disposal system (i.e., the waste package, the mined repository, and the geologic setting). The mathematical relationships used to quantify the conceptual model of the total system in these preliminary analyses are consistent with the level of detail in that conceptual model.

The waste package and the mined-repository components described in Section 6.4.2.1 are contained in the "repository" shown in Figure 6-29. The waste packages are assumed to be uniformly distributed throughout the repository. The radioactivity-release rate $\dot{C}_j$ in curies per year from each waste package is given by

$$\dot{C}_j = a_j f_j(t) \dot{M} \quad (6-5)$$

Figure 6-29. A simple model of proposed waste-disposal system at Yucca Mountain.

where a_j is the specific activity for the j th radionuclide and $f_j(t)$ is the fraction of the inventory mass that remains at time t in the form of the j th radionuclide. The quantity $\dot{M}$ is the mass release rate from the engineered barrier subsystem described in Section 6.4.2.2. Note that the releases of the small fraction of the inventory contained in the pellet-cladding gaps are ignored. The total radioactivity release rate from the engineered barrier subsystem to percolating ground water is simply the release rate from a single waste package times the number of waste packages. In effect, the repository is treated as a planar source term for solutes injected into the unsaturated zone flux.

Water flow through the overburden and the unsaturated tuffs below the repository is assumed to be uniform and downward; the flux is treated as a model parameter that applies only at or below the level of the repository. Flow in the unsaturated zone is as described in sections 6.3.1.1.5 and 6.4.2.2.2. The water flow time in the saturated zone has been ignored because adding the saturated travel time makes little difference in the total travel time, although retardation in the saturated zone would be expected to delay radionuclide transport.

The calculational model used to estimate the transport of radionuclide-bearing compounds from the disturbed zone through the unsaturated tuffs and to the water table is a modification of the model that was used to calculate releases in the draft version of this document. In brief, the model is basically the analytic solution to the one-dimensional dispersionless transport equation for a single-member decay chain (for example, see Harada et al., 1980) with Equation 6-5 representing the time-dependent initial conditions on radionuclide release at the repository level. The analytic solution gives the cumulative, total discharge to the water table (in curies) of one of the three nonretarded species, carbon, iodine, and technetium, as a function of time since closure and of travel time (which is treated as an independent variable in this formulation). The distributions of travel times obtained in Section 6.3.1.1.5 are then used to calculate the expected cumulative discharge of each of the three nonretarded radionuclides up to 10,000 and 100,000 years after closure by integrating the product of the analytic solution and the travel-time distribution over all travel times. For the sake of analytical simplicity, the travel-time distribution is assumed to be normal in these calculations with mean travel times and standard deviations given by the sample means and standard deviations obtained in the numerical simulations of Section 6.3.1.1.5. However, an inspection of the empirical distributions obtained in Section 6.3.1.1.5 show that the travel-time distribution accounting for all travel-times from the disturbed zone to the water table is not a normal distribution; it is skewed towards longer travel times more than would be expected for a normal distribution (see Figure 6-7). The effect of the normal-distribution approximation on the results of this evaluation is therefore to overestimate the curies released to the water table over 10,000 years and slightly underestimate curies released over 100,000 years. The reader is cautioned that this simple calculational model has not been benchmarked or validated, but it has been shown to produce results that agree with more conventional solutions to radionuclide-transport problems.

In the remainder of this section, the performance of the system in two configurations will be calculated with the simple conceptual model just described. The two configurations are as follows:

1. Reference configuration: The reference configuration for the total system is intended to represent conservative estimates of values and conditions that can be supported by the analyses of subsystem and component performance in Section 6.4.2.2. The reference values and conditions developed in Section 6.4.2.2 are collected and summarized in Table 6-49.
2. Performance-limits configuration: The performance-limits configuration is the same as the reference case except that the waste package lifetime is limited to 300 years and the fractional release rate from the engineered-barrier subsystem is varied about 1×10^{-5} per year, the upper limit on fractional release rates defined in 10 CFR 60.113 (1983).

6.4.2.3.2 System analysis

The estimated radioactivity releases to the accessible environment by the model system in the two configurations are listed in Table 6-50. For the reference configuration (upper bound flux value of 0.5 millimeters (0.02 inch) per year), the fractional release rates were assumed to be proportional to the flux, and to occur according to the simple model of the rate of release from the engineered barrier subsystem (Section 6.4.2.2).

For the performance-limits configuration, calculations were made for three values of the release rate that were varied about 1×10^{-5} per year (i.e., 10^{-6} to 10^{-4}); the flux in the performance-limits configuration is arbitrarily set at the upper bound of current flux estimates, 0.5 millimeter (0.02 inch) per year, which corresponds to a physically defensible release rate of about 2.5×10^{-9} per year (Section 6.4.2.2). In order to achieve release rates of 10^{-6} to 10^{-4} per year at this flux, the solubility of the uranium oxide matrix would have to be 100 to 10,000 times larger than the largest value (about 5×10^{-2} kilogram per cubic meter) applying to Yucca Mountain waters (Ogard and Kerrisk, 1984). Such a circumstance is clearly not credible. Fractional release rates briefly exceeding 10^{-4} per year are theoretically possible for the less than 1 percent of the inventories of cesium, iodine, and possibly technetium that are believed to reside in the pellet-cladding gaps of the spent fuel (see Section 6.4.2.2.2), but the average fractional release rate for these components will probably be bounded by the unknown failure rate of the Zircaloy cladding. In any case such sporadic release of less than 1 percent of the inventories of cesium and iodine would have little effect on the releases to the water table indicated under the performance-limits case in Table 6-50.

6.4.2.4 Comparisons with regulatory performance objectives

In this section, the results of the preliminary subsystem performance analyses, Section 6.4.2.2, and the preliminary system performance analyses, Section 6.4.2.3, are compared with applicable regulatory performance objectives. The comparisons are not intended to definitively show that the performance of the subsystems and the total system will meet applicable

Table 6-49. Summary of values and conditions used in preliminary system performance analysis

Item	Reference case (upper bound flux value)	Uncertainty ^a
Waste package lifetime	3,000 yr	3,000 to 30,000 yr
Fractional release rate from engineered barrier subsystem ^b	2.5×10^{-9} per yr	0 to 2×10^{-9} per yr
Flux through repository level	0.5 mm/yr ^c	1×10^{-7} to 0.5 mm/yr
Expected water-flow times between disturbed zone ^d and water table	43,270 yr	30,470 to 56,070 ^e
Retardation factors for unsaturated tuffs	(see Table 6-48)	Consistent with as much as 15 times more or less than Table 6-48 values for distribution coefficients ^f

^aRange of uncertainties in the analyses of components (Section 6.4.2.2).

^bSee Section 6.4.2.2; release rate depends on flux; spent fuel dissolution only (for vertical emplacement).

^cSection 6.3.1.1 reports a matrix flux of less than 0.5 millimeter (0.02 inch) per year.

^dDisturbed zone is assumed to be approximately 50 meters (160 feet) below center plane of repository; see Section 6.3.1.1.5.

^eThese numbers are means of ground-water travel time distributions; full distributions were used in actual calculations.

^fData from Daniels et al. (1982).

regulations. Rather, the regulatory criteria are used to detect areas that require increased study or emphasis. The comparisons may also increase or decrease levels of confidence in the ability of the subsystems and the total system to eventually meet the regulatory performance objectives.

The comparisons are presented in Table 6-51, which lists some of the applicable regulatory criteria, briefly summarizes their content, and presents the relevant findings of sections 6.4.2.2 and 6.4.2.3. Several cautions are warranted: with respect to 40 CFR 191.13 and 191.16 (1985) (items 1 and 3), the likelihood of exceeding the stated release limits is not addressed by the analyses of Section 6.4.2.3, and both the conceptual and

Table 6-50. Preliminary estimates of cumulative radioactivity released to the accessible environment from a repository containing 70,000 metric tons of heavy metal

Release rate per year	Cumulative radioactivity (curies)		Isotope released
	10,000 years ^a	100,000 years ^b	
REFERENCE CASE ^c (upper bound flux of 0.5 millimeter per year)			
(d)	0	1.4 x 10 ⁻²	C-14
(d)	0	0.3	I-129
(d)	0	97	Tc-99
PERFORMANCE-LIMITS CASE ^e (not considered possible at Yucca Mountain)			
1 x 10 ⁻⁶	0	2.8 x 10 ⁻¹	C-14
		6.2	I-129
		1.9 x 10 ³	Tc-99
1 x 10 ⁻⁵	0	2.8	C-14
		6.1 x 10 ¹	I-129
		1.9 x 10 ⁴	Tc-99
1 x 10 ⁻⁴	0	2.7 x 10 ¹	C-14
		5.4 x 10 ²	I-129
		1.7 x 10 ⁵	Tc-99

^aThe ground-water travel-time distributions calculated in Section 6.3.1.1.5 show a negligible but nonzero probability of travel times less than 10,000 years. Accordingly, the calculations of curies released to the accessible environment in Section 6.4.2.3.2 predict releases by 10,000 years that are not exactly zero, but are tiny fractions of the releases permitted by the EPA regulation: for the reference case (upper bound flux value), the curies released in 10,000 years are less than 0.00001 percent of permitted releases; for the three artificial release rates of the performance-limits case, 1×10^{-6} , 1×10^{-5} , and 1×10^{-4} per year, the curies released are respectively less than 0.0002 percent, 0.002 percent, and 0.02 percent of the permitted releases.

^bNote that all cumulative radioactivity values at 100,000 years are below the releases permitted for 10,000 years by 40 CFR Part 191 (1985).

^cSee Table 6-49 text for other parameter values.

^dFractional release rate is 2.5×10^{-9} per year.

^eRelease rate artificially varied; flux maintained at an upper bound of 0.5 millimeter (0.02 inch) per year.

Table 6-51. Comparison of regulatory criteria and the results of preliminary system performance analyses for a repository at Yucca Mountain

Regulatory criterion	Relevant stipulation	Predicted system performance
40 CFR 191.13 containment requirements	"...cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events..." shall have a likelihood of less than 1 chance in 10 of exceeding the quantities calculated according to Table 1 (Appendix A).	Expected releases of radionuclides to accessible environment for 100,000 years do not exceed release limits specified for 10,000 years (Table 6-50).
40 CFR 191.15 individual protection requirements	"...for 1,000 years after disposal. Undisturbed performance of the disposal system shall not cause the annual dose equivalent from the disposal system to any member of the public in the accessible environment to exceed 25 millirems to the whole body or 75 millirems to any critical organ."	Waste package lifetime is expected to greatly exceed 1,000 years; radiation that could affect members of the public would be totally confined over this period (Section 6.4.2.2.1).
40 CFR 191.16 ground-water protection requirements	"...for 1,000 years after disposal, undisturbed performance of the disposal system shall not cause the radionuclide concentrations averaged over any year in water withdrawn from any portion of a special source of ground water to exceed: (1) 5 picocuries per liter of radium-226 and radium-228; (2) 15 picocuries per liter of alpha-emitting radionuclides (including radium-226 and radium-228 but excluding radon); or..."	Waste package lifetime is expected to greatly exceed 1,000 years; soluble radionuclides that could enter ground waters would be totally confined over this period (Section 6.4.2.2.1).

Table 6-51. Comparison of regulatory criteria and the results of preliminary system performance analyses for a repository at Yucca Mountain (continued)

Regulatory criterion	Relevant stipulation	Predicted system performance
10 CFR 60.113 ground-water travel time requirements	Pre-waste-emplacement ground-water travel time shall be at least 1,000 years.	Ground-water travel time to accessible environment is expected to exceed 43,000 years (Section 6.3.1.1).
10 CFR 60.113 waste package containment requirement	Containment of radioactive waste within the waste packages will be substantially complete for a period to be determined by the NRC, but such a period shall not be less than 300 years nor more than 1,000 years after permanent closure of the geologic repository.	Expected waste package lifetime in the Yucca Mountain environment is 3,000 years or more (Section 6.4.2.3).
10 CFR 60.113 long-term release requirement for engineered barrier system	The release rate of any radionuclide from the engineered barrier system following the containment period shall not exceed 1 part in 100,000 per year of the inventory present 1,000 years after closure.	Time-averaged fractional-release rates are expected to be much lower in the Yucca Mountain environment than 1 part in 100,000 per year (Section 6.4.2.3).

mathematical models used in the analyses are oversimplified. With respect to the 10 CFR 60.113 (1983) requirements for the waste package lifetime (item 4), it could be argued that uniform corrosion and stress-corrosion cracking would not be the only mechanisms that contribute to waste disposal container degradation in the Yucca Mountain environment. Other mechanisms could involve the structural failure of the containers because of instability of the surrounding rock. A statistical model of container breaching needs to be developed; such a model would necessarily predict some small release well before the mean lifetime of the container has elapsed. This issue also relates to the release rate of radionuclides after the containment period (item 5). The actual mass-transfer rate appears to be proportional to the area of the waste form exposed to flowing water through breaches in the Zircaloy cladding. The wetted area of waste within the container probably would not increase abruptly, as postulated in the system analyses, but would increase slowly and in a random fashion as time elapsed.

The analysis of system performance in Section 6.4.2.3 represents the performance of the undisturbed waste disposal system. Uncertainties in predicted system behavior were not evaluated, and the possibility that the waste disposal system could be disrupted by unlikely natural events or intentional human intrusion was not considered. These preliminary assessments were performed with limited data and very simple conceptual models.

The preliminary analyses indicate that site characterization activities and studies could profitably focus on the following key uncertainties:

1. Conceptual hydrologic models of flow in the unsaturated zone at Yucca Mountain.
2. The expected physical and chemical environment in the repository for 10,000 years after closure.
3. The conditional waste disposal container lifetime distributions in the postclosure repository environment.

In addition, these and other assessments (e.g., Sinnock et al., 1984) suggest that refinements in the theory of flow and transport in fractured, porous unsaturated rock will be needed before adequate postcharacterization assessments can be made. In particular, methods for treating the stochastic aspects of flow and transport in fractured, porous media need to be developed in order to estimate the effects of hydrodynamic dispersion and chemical retardation on potential radionuclide releases to the accessible environment. A data base containing estimates of the mean values and other statistical quantities for key rock properties is also essential.

6.4.2.5 Preliminary evaluation of disruptive events

The evaluations of the Yucca Mountain site against the postclosure technical guidelines (Section 6.3.1) contain assessments of the effects of many potentially disruptive natural processes on a repository at Yucca Mountain.

Some of the relevant assessments in that section are summarized in this section, which ends with a discussion of the likelihood and consequences of human intrusion after closure.

6.4.2.5.1 Disruptive natural processes

Fracture flow

Travel time calculations in the unsaturated zone, presented in Section 6.3.1.1.5 (Geohydrology), include fracture flow in intervals where the flux of 0.5 millimeter (0.02 inch) per year is greater than the saturated matrix hydraulic conductivity. However, no continuous fracture pathway from the disturbed zone to the water table is included in the calculations. Although the formation of new fractures is considered unlikely because of the highly fractured nature of the potential host rock, one of the disruptive scenarios that will be considered is that of the formation of a new structural feature that could conduct steady hydrologic flow.

A qualitative consequence assessment of such a feature indicates that even in the most extreme case where the feature with steady flow develops instantaneously after repository closure, there is likely to be no release to the accessible environment through the water pathway in the next 10,000 years. Although very rapid transport of any dissolved waste would be possible through the unsaturated zone, travel times in the saturated zone are reported to be at least 140 years under current flux conditions and very conservative assumptions (Section 6.3.1.1.5). Conservative retardation factors (see Section 6.3.1.2.3), which are based on the effectiveness of matrix diffusion in the saturated zone, indicate that radionuclide travel times are likely to be at least 100 times slower than water travel times. This indicates that under current flux conditions, the saturated zone offers a significant protective barrier that will retard radionuclide transport so that U.S. Environmental Protection Agency (EPA) release limits are not likely to be exceeded at the accessible environment under even the most extreme scenarios.

Climatic changes

Under the most extreme climatic changes considered possible at Yucca Mountain during the next 10,000 years, an estimated 100 percent increase in precipitation during a full pluvial could increase recharge by as much as 15 times the present value of 0.5 millimeter (0.02 inch) per year (see Section 6.3.1.4.4 for complete discussion). It should be noted that this scenario is highly conservative and may be unrealistic because as much as two-thirds of the increased precipitation may become runoff rather than recharge. Increased precipitation is likely to cause increased flux and a possible increase in the elevation of the water table beneath the primary repository area. The potential effects of increased water-table altitude are discussed in Section 6.3.1.4.4, where it is explained that even under the maximum position of the water table, a sufficient thickness of unsaturated zone will remain between the repository and the water table to maintain isolation. In addition the protection from unacceptable radionuclide

releases that is offered by the saturated zone will be effective. As summarized under the fracture flow discussion above, the travel time for radionuclides in the saturated zone is expected to be at least 100 times slower than the travel time for water. This provides increased confidence that even under the most extreme, low probability scenarios of a return to full pluvial conditions very soon after repository closure, releases to the accessible environment in 10,000 years are not likely to exceed the EPA release limits.

Extreme erosion

Erosion (Section 6.3.1.5) has proceeded at Yucca Mountain at a rate of less than 1×10^{-4} meter (3.3×10^{-4} foot) per year for the past 300,000 years. Using this rate gives 2.3 million years for the time required to remove the minimum repository overburden of 230 meters (750 feet). Consequently, erosion without major vertical tectonic movement is not a credible disruptive process at Yucca Mountain.

Dissolution

Dissolution (Section 6.3.1.6) of the host rock is not credible at Yucca Mountain. The silica-rich tuffaceous rocks are insoluble under present and expected physical and chemical conditions.

Effects of tectonism

Possible consequences of tectonism were considered in Section 6.3.1.7 (Tectonics), but none are likely to affect waste isolation: faulting is not expected to create new ground-water pathways to the accessible environment or to significantly lower the isolation potential of Yucca Mountain; the occurrence of basaltic eruptions at the site is considered unlikely, and other changes related to such activity are even more unlikely. Although the region surrounding Yucca Mountain has been tectonically active during the Quaternary Period, there is no evidence of extreme activity at Yucca Mountain. The largest historic earthquake within the geologic setting is reported in Section 6.3.1.7 to be a $M = 6$ located about 110 kilometers (68 miles) southwest of the site. Recurrence intervals within the region are reported to be on the order of 25,000 years for $M \geq 7$ earthquakes, 2,500 years for $M \geq 6$ earthquakes, and 250 years for $M \geq 5$ earthquakes. The potential effects of earthquakes on containment and isolation will be evaluated; qualitative assessments suggest that ground motion associated with earthquakes is unlikely to cause disruption of emplaced waste disposal containers. Displacement associated with very large earthquakes could disrupt containers. However, under current flux conditions, insufficient water is available to dissolve and transport wastes in quantities that would exceed release limits at the accessible environment (see Section 6.4.2.3.2). A further barrier is offered by the retardation that is expected in the saturated zone, as discussed above under fracture flow and climate changes. Regarding basaltic eruptions at the site, Crowe et al. (1982) estimate that the cumulative probability that such events will disrupt the site within the next 10,000 years is between 4.7×10^{-4} and 3.3×10^{-6} . All these estimates lie near the probability limits beyond which disruptive events can be classified as not credible.

Human intrusion

Section 6.3.1.8 (Human interference and natural resources) concluded that there would be little incentive for resource exploration of the Yucca Mountain site in the near future. There are no known natural resources that have or are projected to have in the foreseeable future a value great enough to be considered a commercially extractable resource. Thus, as long as some records of resource distribution are available, it is highly unlikely that people will mine or drill at Yucca Mountain.

Limited water resources are present but are not expected to be amenable to exploitation under current or future economic standards and needs. It should be noted that the most likely result of excessive ground-water extraction near the Yucca Mountain site is an increase in the thickness of the unsaturated zone. Thus, in the unlikely event that these water resources are exploited by future generations, the resulting increase in the thickness of the unsaturated zone would improve the isolation potential of the site.

The population density in the area surrounding the Yucca Mountain site is very low (See Section 6.2.1.2). The rugged terrain, arid climate, lack of surface water, and the deep ground-water table in the area are likely to persist in the future and to continue to limit the population density in the immediate vicinity of Yucca Mountain. Therefore, scenarios for human intrusion which involve exploratory drilling that accidentally penetrates a waste container are likely to have very small population effects. In addition, exploratory drilling in the unsaturated zone does not necessarily lead to increased radioactive releases along water pathways. The regulations addressing such human intrusion scenarios (40 CFR 191, Appendix B (1985)) indicate that direct release of ground water from the repository horizon due to natural flow or pumping, and the creation of a high permeability flow path should be considered as the two most severe consequences of such exploratory drilling. With the absence of ground water and the very low expected flux (See Section 6.3.1.1.5), neither of these scenarios are plausible for an unsaturated zone repository. Thus, the only potential radiation exposure would be to the drilling crew due to contact with extracted waste container contents. It may be reasonable to assume that availability of drilling technology would be accompanied by the ability to detect hazardous material, as is suggested in 40 CFR 191, Appendix B (1985). Additionally, the probability of directly penetrating a waste container is considered to be very low, since it involves the compound probability of drilling into the repository and the probability of directly striking a waste container. Consequently, human intrusion does not appear to be a significant disruptive process at Yucca Mountain.

6.4.2.6 Conclusion

The foregoing preliminary performance analyses uncovered no information that indicates that the Yucca Mountain site is unsuitable for further characterization or that it is likely to be disqualified under the postclosure system guideline (Section 6.3.2) after site characterization and more refined analyses of system performance.

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Chapter 7

COMPARATIVE EVALUATION OF NOMINATED SITES

7.1 INTRODUCTION

7.1.1 PURPOSE AND REQUIREMENTS

This chapter presents a comparative evaluation of the five sites nominated as suitable for site characterization: Davis Canyon, Deaf Smith County, Hanford, Richton Dome, and Yucca Mountain (see Figure 7-1). Each site is a preferred site within a geohydrologic setting: Davis Canyon is in the bedded salt of the Paradox Basin in Utah; Deaf Smith County is in the bedded salt of the Permian Basin in Texas; Hanford is in basalt in the Columbia Plateau in Washington; Richton is a salt dome in Mississippi; and Yucca Mountain is in tuff in the Southern Great Basin in Nevada. The process that led to the identification of these sites is described in Chapter 2.

The major objective of this chapter is to present a comparative evaluation of the sites proposed for nomination in order to satisfy the following requirements:

1. Section 112(b)(E)(iv) of the Nuclear Waste Policy Act of 1982 (the Act), which requires that a "reasonable comparative evaluation" be included in the environmental assessments that accompany site nomination.
2. Section 960.3-2-2-3 of DOE's siting guidelines (10 CFR Part 960), which requires that a reasonable comparative evaluation be made and that a summary of evaluations with respect to the qualifying condition for each guideline be provided to "allow comparisons to be made among sites on the basis of each guideline."

This comparative evaluation is intended to facilitate the comparison of the more-detailed suitability evaluations reported for each site in Chapter 6. The comparison should assist the reader in understanding the basis for the nomination of five sites as suitable for characterization (Section 112(b)(1)(A) of the Act); it is not intended to directly support the subsequent recommendation of three sites for characterization as candidate sites.

7.1.2 APPROACH AND ORGANIZATION

This comparative evaluation of the five nominated sites is based on the postclosure and the preclosure guidelines (10 CFR Part 960, Subparts B and C, respectively). The reader is referred to Chapter 6 for a detailed discussion of the structure and the content of the siting guidelines. The evaluation presented in this chapter includes both the system guidelines and the technical guidelines.

Figure 7-1. Sites selected for nomination.

The comparison of the sites against each technical guideline uses the information from the guideline evaluations presented in Chapter 6 of the five environmental assessments, whereas the comparisons against the system guidelines summarize directly the evaluations reported in Chapter 6. The approach used to compare the sites against each technical guideline is summarized below.

In order to facilitate the comparison of sites on the basis of each qualifying condition, major considerations were derived by identifying the favorable, potentially adverse, and disqualifying conditions that deal with the same general topic. Contributing factors representing site characteristics that are potentially important to each major consideration were also identified. The relative importance of the major considerations was determined primarily by the degree to which they contribute to the qualifying condition; that is, the stronger the tie between the consideration and the qualifying condition, the greater the importance of the consideration. Each site was evaluated in terms of each major consideration, taking into account the contributing factors at that site.

The purpose of identifying major considerations for each guideline is to combine closely related site conditions so that the favorable and potentially adverse conditions can be considered on balance. A major consideration may be broader in scope than the combined scope of the related favorable and potentially adverse conditions, in order for it to relate more directly to the qualifying condition. Most guidelines that contain a disqualifying condition have one or more potentially adverse conditions that are related to the disqualifying condition. Since these potentially adverse conditions are considered in the formulation of a major consideration, the important aspects of the disqualifying conditions indirectly enter the comparative evaluation. Where a major consideration that is needed to evaluate the qualifying condition does not have a related favorable or potentially adverse condition, the consideration is derived directly from the qualifying or disqualifying condition. Not all contributing factors are discussed for each site; for brevity, only the factors that contribute to the evaluation of that consideration are discussed. The evaluation of each site with respect to each major consideration is presented in alphabetical order, by site.

The major considerations for the guidelines were then considered collectively, taking into account their relative importance, in a comparative evaluation of the sites. This comparative evaluation describes the sites with the most favorable combination of characteristics first and those with a less favorable combination of characteristics last.

The comparative evaluations of the sites are summarized in Sections 7.2 and 7.3 for the postclosure and the preclosure guidelines, respectively.

7.2 COMPARISON OF THE SITES ON THE BASIS OF THE POSTCLOSURE GUIDELINES

The postclosure guidelines are concerned with the characteristics, processes, and events that may affect the performance of the repository after closure. The objective is to ensure that the health and safety of the public will be protected for thousands of years, until the radioactivity of the waste

has diminished to safe levels. This section presents a comparative evaluation of the five nominated sites against the postclosure guidelines.

7.2.1 TECHNICAL GUIDELINES

7.2.1.1 Geohydrology (postclosure)

The qualifying condition for geohydrology is as follows:

The present and expected geohydrologic setting of a site shall be compatible with waste containment and isolation. The geohydrologic setting, considering the characteristics of and the processes operating within the geologic setting, shall permit compliance with (1) the requirements specified in 10 CFR 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.

Major considerations

On the basis of the favorable and potentially adverse conditions for this guideline, four major considerations (see Table 7-1) are identified that influence the favorability of the site with respect to the qualifying condition. These major considerations, in decreasing order of importance, are (1) ground-water travel time and flux, (2) changes in geohydrologic processes and conditions, (3) ease of characterization and modeling, and (4) presence of suitable ground-water sources. These major considerations are, in turn, influenced by a number of more specific geologic and hydrologic properties and in situ conditions called contributing factors.

Evaluation of the sites with respect to major considerations

Ground-water travel time and flux. This consideration covers the geohydrologic conditions that control the time of ground-water travel between the disturbed zone and the accessible environment and the ground-water flux (volumetric flow rate) across or through the repository and through the host rock to the accessible environment. It is related directly to the qualifying condition as a measure of the amount of ground water that can come in contact with the waste, the amount of ground water available to transport radionuclides between the repository and the accessible environment, the time delay for these radionuclides to reach the accessible environment, and the time available for radioactive decay during transport. This major consideration is derived from the first, fourth, and fifth favorable conditions of the geohydrology guideline. It is the most important of the major considerations because transport by ground water is the primary mechanism for radionuclide movement from the repository to the accessible environment.

The contributing factors for this consideration include the hydraulic conductivity and gradient, the effective porosity, the degree of saturation, the depth to the water table, the presence of flow through fractures or porous

Table 7-1. Guideline-condition findings by major consideration--geohydrology^{a,b}

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: GROUND-WATER TRAVEL TIME AND FLUX					
Favorable condition 1					
Site conditions such that the pre-waste- emplacement ground-water travel time along any path of likely radionuclide travel from the disturbed zone to the accessible environment would be more than 10,000 years.	P	P	P	P	P
Favorable condition 4					
For disposal in the saturated zone, at least one of the following pre-waste-emplacement conditions exists:	P	P	P	NP	NA
(i) A host rock and immediately surrounding geohydrologic units with low hydraulic conductivities.	P	P	NP	NP	NA
(ii) A downward or predominantly horizontal hydraulic gradient in the host rock and in the immediately surrounding geohydrologic units.	NP	P	NP	NP	NA
(iii) A low hydraulic gradient in and between the host rock and the immediately surrounding geohydrologic units.	NP	NP	P	NP	NA
(iv) High effective porosity together with low hydraulic conductivity in rock units along paths of likely radionuclide travel between the host rock and the accessible environment.	NP	NP	NP	NP	NA
Favorable condition 5					
For disposal in the unsaturated zone, at least one of the following pre-waste- emplacement conditions exists:	NA	NA	NA	NA	P
(i) A low and nearly constant degree of saturation in the host rock and in the immediately surrounding geohydrologic units.	NA	NA	NA	NA	NP
(ii) A water table sufficiently below the underground facility such that the fully saturated voids continuous with the water table do not encounter the host rock.	NA	NA	NA	NA	P
(iii) A geohydrologic unit above the host rock that would divert the down- ward infiltration of water beyond the limits of the emplaced waste.	NA	NA	NA	NA	NP
(iv) A host rock that provides for free drainage.	NA	NA	NA	NA	P
(v) A climatic regime in which the average annual historical precipitation is a small fraction of the average annual potential evapotranspiration.	NA	NA	NA	NA	P

Table 7-1. Guideline-condition findings by major consideration--geohydrology^{a,b} (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 2: CHANGES IN GEOHYDROLOGIC PROCESSES AND CONDITIONS					
Favorable condition 2					
The nature and rates of hydrologic processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years.	P	P	P	P	NP
Potentially adverse condition 1					
Expected changes in geohydrologic conditions--such as changes in the hydraulic gradient, the hydraulic conductivity, the effective porosity, and the ground-water flux through the host rock and the surrounding geohydrologic units--sufficient to significantly increase the transport of radionuclides to the accessible environment as compared with pre-waste-emplacement conditions.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 3: EASE OF CHARACTERIZING AND MODELING					
Favorable condition 3					
Sites that have stratigraphic, structural, and hydrologic features such that the geohydrologic system can be readily characterized and modeled with reasonable certainty.	NP	NP	NP	NP	NP
Potentially adverse condition 3					
The presence in the geologic setting of stratigraphic or structural features--such as dikes, sills, faults, shear zones, folds, dissolution effects, or bring pockets--if their presence could significantly contribute to the difficulty of characterizing or modeling the geohydrologic system.	P	P	P	P	P
MAJOR CONSIDERATION 4: PRESENCE OF SUITABLE GROUND-WATER SOURCES					
Potentially adverse condition 2					
The presence of ground-water sources, suitable for crop irrigation or human consumption without treatment, along ground-water-flow paths from the host rock to the accessible environment.	NP	NP	NP	NP	P

^a Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

^b Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

media, net infiltration, the extent of the disturbed zone, and the distance to the accessible environment.

At each of the sites there are uncertainties in the conceptual model of ground-water flow, including the values of the key hydraulic parameters that control ground-water travel time and flux. Taking the uncertainties into account, there are ranges of possible travel times between the disturbed zone and the accessible environment at each site. Therefore, ground-water travel time was stochastically modeled at each site, using reasonably conservative geohydrologic assumptions and ranges of hydraulic parameters. Probabilistic ranges in travel time and the statistical probability for exceeding travel times of 1,000 and 10,000 years were derived for each site. In general, the ground-water flux is expected to be low to very low at each of the sites. A summary of the evaluation for each site follows.

At Davis Canyon, ground-water travel times from the disturbed zone to the accessible environment are modeled as porous-media flow vertically and horizontally through a layered sequence of differing lithologies (salts, anhydrite, dolomite, siltstone, etc.). The calculated travel times depend on the hydraulic conductivity and the effective porosities of the varying lithologies, the thickness and continuity of each layer, and the vertical and horizontal hydraulic gradients within and between each layer. Because the values of these parameters are uncertain, the expected ground-water pathways are uncertain. To quantify this uncertainty at Davis Canyon, a computer code was developed to evaluate the probability the distribution of travel times based on distribution of hydrologic parameters derived from data collected at a DOE test well (Gibson Dome No. 1) 5 kilometers (3 miles) north of the site, various oil test wells in the Paradox Basin, and various published sources of generic data. For purposes of analyzing the ground-water travel time, the outer edge of the disturbed zone was conservatively assumed to be at the top and bottom of the host salt bed, because of uncertainty in the extent of the disturbed zone. The time required for ground water to travel through the host salt bed is not included in the calculations of pre-waste-emplacement travel time to the accessible environment. The overall regional vertical hydraulic gradient between the upper and the lower hydrostratigraphic units, separated by the evaporite section containing the host salt bed, is generally downward. However, data collected at the Gibson Dome test well indicate both local downward and upward gradients between interbeds in the evaporite section containing the proposed host salt bed. The combined vertical and horizontal gradients in the area then result in either upward-to-lateral flow or downward-to-lateral flow within the layered sequence. Both the upward-to-lateral and downward-to-lateral travel times are analyzed, resulting in quite similar distributions.

The proposed controlled-area boundary for the Davis Canyon site is limited to a distance of 1 kilometer (0.6 mile) from the edge of the disturbed zone to the accessible environment due to the proximity of Canyonlands National Park in the expected direction of ground-water flow. For a lateral distance of 1 kilometer (0.6 mile) from the outer edge of the disturbed zone to the accessible environment, downward-to-lateral travel times were stochastically analyzed through 1,000 realizations of the model. This results in a probability of .003 for travel times of less than 1,000 years and probability of a .045 for less than 10,000 years. The median travel time is 240,000 years. A distance of 5 kilometers from the edge of the repository was also analyzed in case the boundary of the controlled area should change as a

result of data developed during site characterization in a direction away from the Canyonlands National Park. This analysis results in a probability of less than 0.001 for travel times of less than 1,000 years and .006 for less than 10,000 years, with a median travel time of 880,000 years.

The Deaf Smith site is in a geohydrologic setting that is conceptually similar to that of the Davis Canyon site. A similar stochastic analysis of pre-waste-emplacement ground-water travel time was made. The computer flow model, as for Davis Canyon, consists of a series of layers representing a sequence of differing lithologies (salt, anhydrite, dolomite, siltstone, etc.), including the host salt bed. Only downward-to-lateral travel times were calculated, because only downward vertical hydraulic gradients have been observed in the vicinity of the site. The travel time was calculated beginning at the bottom of the salt repository bed (considered conservatively as the bottom edge of the disturbed zone) and extending 1 kilometer to the accessible environment. To consider the possibility that the boundary of the controlled area (and the distance to the accessible environment) might be extended, travel times were also calculated to the maximum 5-kilometer distance from the edge of the disturbed zone. The modeling is based on data obtained from literature reviews, analyses of water-well and petroleum-well records and pump testing, analyses of drill-stem tests, and analyses of laboratory tests conducted specifically for the repository program. There is a comparable level of uncertainty in the data bases for the Deaf Smith and the Davis Canyon sites. Considering porous-media flow as the likely flow mechanism, the results of travel-time analyses for an accessible environment 1 kilometer from the edge of the disturbed zone, on the basis of 1,000 realizations of the model, show a probability of .005 for travel times of less than 1,000 years and a probability of .107 for less than 10,000 years, with a median travel time of 87,000 years. For an accessible environment 5 kilometers from the edge of the disturbed zone, the probability of travel times of less than 1,000 years is less than .001, and the probability for less than 10,000 years is .015, with a median travel time of 500,000 years.

At the Hanford site, the stochastic analysis of the pre-waste-emplacement ground-water travel time used a conceptual model that is consistent with the current understanding of the deep ground-water flow system and considers the uncertainties in the hydraulic parameters used to predict travel times. In the analysis, ground-water flow is modeled along upward and lateral flow paths through an alternating sequence of basalt flows in which dense interiors of low permeability are separated by flow tops of higher permeability. The vertical and horizontal hydraulic-head gradients used in the stochastic model are deterministic; that is, they are based on quality head data obtained from piezometers at the site. The transmissivity values used in the model were based on site-specific test data that were varied over a reasonably conservative range. The range of effective porosity was estimated from geophysical logs, core samples, two tracer tests, and values reported in the literature. Key hydraulic parameters were conservatively evaluated over appreciable ranges in the model. The model considers ground-water movement that begins in the flow top immediately above the dense flow interior (the outer edge of the disturbed zone being within the dense interior host rock at an unknown distance from the flow top) of the proposed host rock and proceeds vertically upward and laterally to the accessible environment, 5 kilometers from the edge of the repository. The model conservatively does not include vertical travel time through the upper part of the undisturbed dense interior between the proposed repository and the base of the first flow top above the

repository. The range of travel times derived from the model indicates a probability of .03 or less for travel times of less than 1,000 years and a probability of .22 or less for travel times of less than 10,000 years. This compares with the shortest median travel time for the conservative analyses of 22,000 years.

At the Richton site, the accessible environment is considered to be at the flank, or periphery, of the salt stock; therefore, ground-water travel times from the disturbed zone to the accessible environment (a minimum lateral distance of 244 meters (800 feet)) are judged to be within essentially pure salt. The mechanism for ground-water movement through the salt is uncertain. Because of the ductility of salt, which reduces the likelihood of open fractures, and the extremely low matrix hydraulic conductivity and porosity, there may be little or no water movement through the salt. However, to evaluate the travel time from the edge of the disturbed zone to the accessible environment, porous-media flow was conservatively assumed to prevail in the salt. Preliminary geologic studies have not identified anomalous features that would indicate the presence of preferential permeable flow paths in the salt stock. Fracture flow is considered unlikely and is not considered in the model. Flow is assumed to obey Darcy's law, and conservative ranges of the key hydraulic parameters are used; they are based on available generic in situ and laboratory data, including geophysical well logs. No site-specific data on hydraulic parameters are available. If alternative mechanisms of movement (e.g., diffusion) are considered, the estimated travel times to the accessible environment would be several million years.

The results of the stochastic modeling show a probability of less than .001 for travel times less than 1,000 or 10,000 years to the flank of the dome. Because of the very low hydraulic conductivities measured for essentially pure salt, the calculated times of lateral travel through 244 meters (800 feet) of salt are very long. Stochastic model calculations range over six orders of magnitude--the shortest being about 50,000 years and the median about 35 million years. Although the ranges of hydraulic parameters used in the analysis are considered reasonably conservative, a great deal of uncertainty is inherent in any prediction of travel times in millions of years. Of more significance than the absolute numbers, perhaps, is that the very long travel times suggested by the analysis indicate a likelihood that little or no ground water is present or moving through an appreciably thick, undisturbed mass of salt.

At Yucca Mountain, the stochastic analysis of the pre-waste-emplacement ground-water travel time from the disturbed zone to the accessible environment computes vertical ground-water movement downward through the unsaturated zone to the water table and then 5 kilometers laterally in the saturated tuff to the accessible environment. Travel time is calculated from a horizon 50 meters (164 feet) below the proposed repository downward through a minimum of about 135 meters (443 feet) of unsaturated welded and nonwelded tuff to the water table. Most of the total travel time is through the unsaturated zone, with about 140 years estimated for the travel time through the saturated zone to the accessible environment, once the water table is reached. Uncertainty in the variability and ranges in hydraulic conductivity and effective porosity are evaluated stochastically in the model, by randomly selecting ranges in hydraulic parameters in a series of 963 vertical columns. The calculated travel times range from about 9,500 to 80,250 years. This is based on an

estimated maximum average net percolation of 0.5 millimeter per year. Ten realizations were run in each of the 963 columns of the model, with all but one of the 9,630 total realizations having a travel time of more than 10,000 years. The mean travel time in these calculations was about 43,300 years, and the median about 41,600, with a probability of about .0001 for a travel time of less than 10,000 years.

Changes in geohydrologic processes and conditions. This consideration covers the nature and rate of natural processes in the geologic setting that could ultimately change geohydrologic conditions so as to affect the ability of a repository to isolate the waste. It is directly related to the qualifying condition, which requires that geohydrologic conditions in the future be compatible with waste isolation. It is derived from the second favorable condition and the first potentially adverse condition. This consideration is second in importance because the preceding consideration, the ground-water travel time, reflects actual conditions, whereas this consideration reflects potential conditions.

Four contributing factors are identified for this consideration: climatic change, erosion, dissolution, and tectonics. On the basis of the discussion of these factors in Section 6.3.1 of each environmental assessment, it was concluded that climatic change is the only one of the four contributing factors that has a potential for significantly affecting the hydrologic system at any of the nominated sites during the next 100,000 years. Therefore, climatic change is the only potential cause of changes in the geohydrologic system that is addressed in the summary of site evaluations.

Judging from the record of the Quaternary Period in the area of the Davis Canyon site, climatic changes during pluvial conditions could increase precipitation, with a resulting increase in recharge to the ground-water system. Although it is uncertain to what extent higher rates of precipitation during the Quaternary Period have affected the hydrologic system, there is no evidence that ground-water parameters have changed significantly during the Quaternary Period. Also, the low permeability of the evaporite section separating the shallow hydrologic system from the deep confined system is expected to preclude any significant effects from expected climatic changes. Assuming that climatic changes during the next 100,000 years would be within the magnitude of past changes during the Quaternary Period, it does not appear that expected changes would adversely affect waste isolation at the Davis Canyon site during the next 100,000 years.

Judging from the record of the Quaternary Period, precipitation may be expected to increase over the current levels for the area of the Deaf Smith site, with consequent increases in recharge during the next 100,000 years. However, because of the low permeability of the evaporite section and the fine sedimentary interbeds that separate the shallow hydrologic system from the deep confined system beneath the proposed repository horizon, the variations in the nature and rates of surficial hydrologic processes that would result from future climatic changes would have little effect on the ability of a repository at the site to isolate waste during the next 100,000 years.

The climatic history of the Quaternary Period at the Hanford site indicates that any hydrologic impacts due to climatic changes would be localized or shallow phenomena (e.g., glacially induced flooding) that would

not significantly change the waste-isolation potential of the deep basalt environment during the next 100,000 years. The factors responsible for this include the low permeability of the basalt flow interiors between the land surface and the proposed repository depth; the relatively low permeability of the deep basalt flows in comparison with shallow flows and interbeds; the existence of different flow systems with depth; the short duration of floods; and the likely persistence of the arid to semiarid climate that has existed at Hanford over the past 3 million years.

For the Richton site, the Quaternary history of the region indicates that climatic changes would have no significant influence on geohydrologic conditions at the site. Variations in geohydrologic processes that have occurred in response to Quaternary climatic cycles and the associated sea-level fluctuations result in slight increases and decreases in precipitation, hydraulic gradients, and rates of ground-water movement in the geohydrologic system surrounding the salt dome. Because of the very low hydraulic conductivity of the dome salt, such slight variations in hydrologic processes are expected to have minor, if any, effects on fluid movement within the dome. Therefore, no natural geohydrologic changes that would affect waste during the next 100,000 years are expected at the site.

At Yucca Mountain, the climatic record of the Quaternary Period suggests that pluvial conditions may recur sometime during the next 100,000 years, resulting in increased net infiltration (flux) and recharge, which could in turn raise the level of the water table toward the repository. Such changes would tend to reduce the time of ground-water travel between the disturbed zone and the accessible environment and could result in some increase in the quantity of ground water coming in to contact with the waste.

Ease of characterization and modeling. This consideration addresses the complexity of the geohydrologic system in terms of whether it can be characterized and modeled with reasonable certainty. It relates to the qualifying condition because characterization is the process of collecting and analyzing the data needed to develop and perform the modeling that is the means for predicting whether the site is compatible with waste containment and isolation. This major consideration is derived from the third favorable condition and the third potentially adverse condition. Since it is not an intrinsic physical characteristic of the geohydrologic setting, this consideration is not as important as the first two considerations; however, the ability to characterize and model the geohydrologic system with reasonable certainty is essential to evaluating the geohydrologic processes and properties that affect the ability of the site to contain and isolate waste.

Some of the contributing factors that influence the ease of characterization and modeling are the presence of faults, folds, brine pockets, dissolution effects, lithologic variations, interrelationships among hydrostratigraphic units, availability of testing techniques and analytic models, and understanding of flow mechanisms.

All five nominated sites are, to varying degrees, presently judged to have geologic and hydrologic complexities that could preclude their being readily characterized or modeled with reasonable certainty. Appreciable differences exist from one site to another in present levels of uncertainty, in part because of imbalances in the quality and quantity of available data

and stages of scientific and technical investigation. A good understanding of the geohydrology of the site must be developed through the characterization process before it can be modeled with reasonable certainty. Modeling, in turn, can determine which physical characteristics need to be characterized. The difficulty of characterizing a site limits the ability to model it to an acceptable level of certainty. Although the third favorable condition is not present and the third potentially adverse condition is present at each site, it is expected that all five sites can be adequately characterized, though with varying levels of difficulty, in order to model their capabilities for long-term waste isolation to acceptable levels of certainty. A summary of the evaluation for this consideration for each site follows.

At the Davis Canyon site, the regional geologic framework and limited site-specific data suggest that the site is stratigraphically and structurally uncomplicated. Present stratigraphic information indicates that the proposed host salt bed contains minimal impurities and is a part of a reasonably well-understood sedimentary sequence. However, the present limited investigations leave many uncertainties. Structural features like faults, folds, and dissolution zones within the geologic setting could contribute to the difficulty of characterizing the system if they are found within the site. Ground-water movement through deep salt beds may be practically nil. There is a need to develop a clear understanding of the movement of fluids in salt and a site-specific ground-water hydraulics data base and to evaluate the potential for significant fracture flow in hydrogeologic units surrounding the host rock.

Because they are in similar geohydrologic settings, the Deaf Smith site and the Davis Canyon site are similar with respect to the ease of characterizing and modeling. Somewhat more data are presently available for the Deaf Smith site than for Davis Canyon, but fewer site-specific data are available for the salt sites than for the nonsalt sites. The greater number and frequency of nonsalt interbeds at Deaf Smith introduces complicating factors that are less likely to be present at Davis Canyon. As at Davis Canyon, the potential for significant fracture flow in geohydrologic units surrounding the host rock at Deaf Smith needs to be evaluated.

Generically, the horizontal distribution, variations in thickness and internal variations in the thickness of multiple basalt flows like those at Hanford may be more difficult to predict with confidence than for a sequence of sedimentary rocks like those formed at the bedded-salt sites, but site-specific investigations are more advanced at the Hanford site than at any of the salt sites. Consequently, the data base is appreciably larger and the complexities of site characterization and modeling are better defined at Hanford. Geologic features like faults, folds, internal variations in the thickness of flows, and variations in original intraflow structures known to exist in the regional setting could contribute to difficulty in modeling. Although uncertainties remain, preliminary studies have defined some basic geologic and hydrologic characteristics of the site. The existence of multiple basalt flows can complicate the characterization and modeling of the flow system, as well as provide multiple barriers to fluid movement. Accepted concepts and methods for studying saturated flow in a layered geohydrologic system are applicable to the basalt-flow system beneath Hanford. In some ways this may make characterization and modeling less complicated than at sites where applicable fluid-flow theory is either more complex or less advanced, such as for flow in salt or in the unsaturated zone at Yucca Mountain.

At the Richton site, the boundaries and dimensions of the salt stock are reasonably well defined. Limited available data on the interior characteristics of the salt stock suggest that it consists largely of pure salt that is free of significant anomalous features (e.g., large faults or clastic inclusions) that would provide important preferential ground-water flow paths. However, this concept of the dome's interior is uncertain and requires additional data for confirmation. Also, data on the surrounding geohydrologic environment mainly provide a regional picture of the ground-water flow system outside the dome, with little site-specific information to define flow relationships near the interface of the salt stock and the adjacent hydrostratigraphic units. These relationships may be complex and difficult to characterize, requiring an extensive data base that would be difficult to acquire. The characteristics of ground-water movement, if any, within salt are not well understood. Therefore, there is uncertainty in how to characterize and model fluid movement within the dome and any exchange of ground water between the dome and the surrounding geohydrologic units. On the other hand, because the accessible environment at the Richton Dome begins at the edge of the salt stock, the controlled area extends only to the periphery of the dome. The most critical part of the geohydrologic system to be characterized and modeled is confined to what may be an essentially homogeneous medium, the interior salt mass of the dome. In this respect, the flow system may be regarded as less complex and difficult to characterize and model than a system that contains a variety of lithologies or flow media between the repository and the accessible environment. However, the mechanism for ground-water flow in the salt, if such flow is significant, needs to be clearly defined during site characterization.

The geologic setting at Yucca Mountain may be considered somewhat complex, considering the structural history and volcanic origin of Yucca Mountain, and the inherent uncertainties in predicting the lateral and vertical variability of volcanic rock units. Also, the site is relatively complex from the standpoint of the availability of state-of-the-art models for measuring and analyzing flow in the unsaturated zone rather than the saturated zone. Known local faulting adds to the complexity of site characterization and modeling. However, the progress of site-specific geologic and hydrologic investigations is comparable to that at the Hanford site and more advanced than those performed at any of the salt sites. A preliminary site-specific geohydrologic data base has been established, and preliminary details of a conceptual flow model of the unsaturated zone, are defined. Advanced techniques are being developed to measure and analyze hydrologic parameters and to provide the information needed to refine models of flow in the unsaturated zone. Because of the need to develop advanced techniques and methods, the difficulty of characterizing and modeling the site with reasonable certainty may be greater than at sites in the saturated zone where currently accepted methods may be adequate for characterizing and modeling.

Presence of suitable ground-water sources. This consideration addresses the potential for radionuclides migrating from a repository to mix with ground-water sources suitable for crop irrigation or human consumption without treatment along flow paths to the accessible environment. It pertains to the qualifying condition with respect to limitations on radionuclide releases to the accessible environment and is derived from the second potentially adverse condition. This consideration is less important than the other three, because

it is unlikely that ground-water resources could be contaminated if a site is selected on the basis of its ability to isolate wastes, as reflected in the other three considerations. Of the five nominated sites, only Yucca Mountain has a finding of present for the second potentially adverse condition. A summary of the evaluation for each site follows.

At Davis Canyon a low-yielding aquifer containing good-quality ground water is present at a relatively shallow depth above the proposed repository horizon. However, ground water of good quality usable for irrigation or human consumption without treatment is not present along probable ground-water flow paths between the disturbed zone and the accessible environment. Although there is some potential for locally upward flow from the host rock, flow paths would be diverted laterally or downward at least hundreds of meters below the shallow aquifer because of the regionally downward vertical gradient below the shallow aquifer.

At the Deaf Smith site, ground-water flow is expected to be downward from the repository horizon. Water along this flow path has high total-dissolved-solids concentrations, making it unusable for crop irrigation or human consumption without treatment. There is good-quality ground water at shallow depths above the proposed repository horizon, but upward flow is not expected from the host rock.

At the Hanford site, shallow aquifers containing water of good quality exist above likely flow paths from the preferred repository horizon. However, ground water along likely flow paths between the disturbed zone and the accessible environment contains flouride, boron, and sodium concentrations considered too high for crop irrigation or human consumption without treatment.

At the Richton site, the accessible environment is considered to be at the flank of the salt stock. Therefore, ground water suitable for crop irrigation or human consumption without treatment does not occur along ground-water flow paths between the disturbed zone and the accessible environment.

At Yucca Mountain, flow paths from the disturbed zone in the unsaturated zone would be expected to be vertically downward to the water table and then laterally through the saturated zone to the accessible environment. Ground water along the flow paths in the saturated zone is of good quality and suitable for crop irrigation and human consumption without treatment.

Summary of the comparative evaluation

The Richton Dome is the most favorable of the five nominated sites for the geohydrology guideline on the basis of the four major considerations addressed under this guideline. Although site-specific data are sparse, resulting in appreciable uncertainty about flow in geohydrologic units surrounding the dome, and the mechanism of fluid flow in salt is uncertain, ground-water travel times at Richton are expected to be very long, and very little, if any, ground-water movement takes place within the salt stock. It is likely that no ground water or only very little is contained in the salt stock. Uncertainty with respect to the possible presence of anomalous features that could significantly affect flow through the dome would be addressed during site characterization. Hydrologic processes and conditions are not expected to change in a manner that would unfavorably affect the

ability of the repository to isolate waste. Modeling of the geohydrologic system surrounding the dome is expected to be difficult. The limited data base results in appreciable uncertainty about relationships between the dome and the surrounding system. However, because all pathways to the accessible environment are expected to be entirely within the salt host rock, there is a high level of certainty that no usable ground-water sources would be encountered along pathways to the accessible environment.

Davis Canyon is the next most favorable site with respect to the geohydrology guideline if it is compared to Deaf Smith on the basis of equal distances to the accessible environment. It is slightly less favorable than the Richton Dome on the first and most important major consideration and is equally favorable with the other sites on the second major consideration. The pre-waste-emplacement travel time from the disturbed zone to the accessible environment appears to be less than that at the Richton Dome, and the travel time at Davis Canyon is longer than at the Deaf Smith site for equal distances to the accessible environment at both sites. The ground-water flux through the salt host rock, as indicated by the generic understanding of the hydraulic properties of salt, may be small if not nonexistent. There is no evidence for natural geohydrologic changes that will unfavorably affect the ability of the repository to isolate the waste during the next 100,000 years. On the basis of regional geologic studies, the structure and stratigraphy of the site are considered uncomplicated, but because of uncertainties with respect to the mechanism for ground-water flow in salt and the unlikely potential occurrence of a really extensive, fracture-controlled pathways in the brittle sedimentary interbeds, the level of difficulty in characterizing and modeling the geohydrologic system with reasonable certainty is expected to be comparable with that of the other sites. No aquifers containing ground water that is usable without treatment are present along any likely ground-water pathways between the edge of the disturbed zone and the accessible environment.

The Deaf Smith site is less favorable than the Richton and the Davis Canyon sites for the geohydrology guideline when the accessible environment is equally distant from the disturbed zone at Deaf Smith and at Davis Canyon. In such a case, it is less favorable on the first and most important major consideration, but equally favorable on the second major consideration. The estimated pre-waste-emplacement ground-water travel time between the disturbed zone and the accessible environment is shorter than that at Davis Canyon and Richton. However, if the distance to the accessible environment at Deaf Smith should be lengthened up to 5 kilometers and at Davis Canyon remain at 1 kilometer, Deaf Smith would be the more favorable site with respect to the pre-waste-emplacement ground-water travel time. Although the ground-water flux within the salt host rock is expected to be low, the presence of fine clastic interbeds in the host rock results in a potential for higher flux at Deaf Smith than at Davis Canyon or Richton. No natural changes in geohydrologic conditions that would unfavorably affect the ability of the site to isolate waste during the next 100,000 years are indicated. The structure and stratigraphy of the Deaf Smith site, on the basis of regional geologic studies, are considered uncomplicated. Because of uncertainties with respect to the mechanism for ground-water flow in salt and the unlikely potential for areally extensive, fracture-controlled pathways in the brittle interbeds, the level of difficulty in characterizing and modeling the geohydrologic system is expected to be comparable with that of the other sites. Finally, there is a

high level of certainty that no aquifers containing ground water usable without treatment are present along ground-water pathways between the edge of the disturbed zone and the accessible environment.

The Hanford and the Yucca Mountain sites are both less favorable than the salt sites, but are in a comparable range of favorability with each other. Their comparative evaluations vary from one major consideration to another on the basis of available information. With respect to the pre-waste-emplacement ground-water travel time, Yucca Mountain is more favorable than the Hanford site. At Yucca Mountain, the ground-water flux through the host rock and the surrounding geohydrologic units, as indicated by the estimated maximum annual infiltration of 0.5 millimeter, is expected to be very low. A return to pluvial climatic conditions could increase the flux rate through the host rock and the surrounding geohydrologic units. This could also cause some rise in the water table toward the repository and some reduction in the time of travel to the accessible environment. Yucca Mountain and Hanford appear to have similar ranges of structural and stratigraphic complexity with unique geohydrologic complexities at each site. The complexity of fracture systems at Yucca Mountain may have important implications for characterizing and modeling flow in the unsaturated zone with reasonable certainty. Uncertainty in how to model flow in the unsaturated zone may also add to the difficulty of characterizing and modeling at Yucca Mountain. Ground-water sources of good quality are located along likely ground-water pathways from the proposed repository to the accessible environment at Yucca Mountain.

At the Hanford site, the ground-water flux through the saturated host rock and the surrounding geohydrologic units may be higher than in the unsaturated zone at Yucca Mountain. For the second major consideration, Hanford is more favorable than Yucca Mountain. Expected natural changes in hydrologic processes or geohydrologic conditions are not expected to affect the ability of a repository to isolate the waste during the next 100,000 years. Although commonly used modeling techniques may be applied, uncertainties in the structural and stratigraphic heterogeneity of the multiple basalt flows may contribute to modeling difficulties. At Hanford, no sources of ground water suitable for crop irrigation or human consumption without treatment are present along likely ground-water pathways from the edge of the disturbed zone to the accessible environment.

7.2.1.2 Geochemistry

The qualifying condition for postclosure geochemistry is as follows:

The present and expected geochemical characteristics of a site shall be compatible with waste containment and isolation. Considering the likely chemical interactions among radionuclides, the host rock, and the ground water, the characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in §960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-2), three major considerations are identified that influence the favorability of the site with respect to the qualifying condition are identified. In order of decreasing importance, they are (1) the expected rate of mass transfer of radionuclides from the waste package, (2) geochemical conditions that would inhibit the transport of radionuclides into the accessible environment, and (3) geochemical effects on the sorptive properties and strength of the host rock.

Evaluation of the sites in terms of the major considerations

Mass transfer of radionuclides. This consideration includes geochemical conditions in the immediate vicinity of the waste package after the permanent closure of the repository. It relates directly to the qualifying condition through the rates of radionuclide dissolution from the waste form and is based on the second and fourth favorable conditions and the first potentially adverse condition. The mass transfer of radionuclides is the most important consideration because it describes the processes by which radionuclides that are initially sealed in the solid waste form as part of the waste package will be released to the ground-water system (e.g., as ions, complexes, or particulates) or be contained within the engineered-barrier system. The most important contributing factors are the volumetric flow rate of the ground water that may contact the waste package and the chemistry of the ground water. Other contributing factors include the potential for the precipitation and sorption of radionuclides; the potential for the formation of colloids, complexes, and particulates; oxidation-reduction conditions; and the chemical reactivity of the ground water. A summary of the evaluation for each site follows.

The bedded salt of the Davis Canyon site contains little ground water. Sources of water in the repository horizon include brine inclusions and water of carnallite hydration, which constitute a small fraction of the host-rock volume. Thus, the volumetric flow rate of ground water due to the migration of these waters at the repository horizon is expected to be extremely low, if present at all. Because of their high magnesium content, the brines at Davis Canyon are potentially very corrosive for the stainless-steel container of the waste package. However, waste-package degradation should be limited because the amount of water in contact with the waste is expected to be small. The formation of some colloids will be inhibited by the high salinity of brine. Because of their high concentration in the brines, chlorides, sulfates, and carbonates could form complexes with radionuclides, which may increase the mobility of some radionuclides. Although chemically reducing conditions are expected in the host rock and the underlying aquifers, the ability of the water-rock system to maintain reducing conditions in the presence of alpha and gamma radiolysis may be limited.

The host rock at the Deaf Smith site is bedded salt that may contain more water than the rock of the other two salt sites. The salt of the lower San Andres Unit 4 contains intercrystalline muds and interbeds of mudstone containing clay; these muds and interbeds could contribute water in addition to that provided by brine inclusions. Thus, the total amount of ground water that is expected to enter the repository through brine migration should be extremely small. These brines have a high magnesium content and are

Table 7-2. Guideline-condition findings by major consideration—geochemistry^{a, b}

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: EXPECTED RATE OF MASS TRANSFER FROM THE WASTE-PACKAGE SUBSYSTEM					
Favorable condition 2.					
Geochemical conditions that promote the precipitation, diffusion into the rock matrix, or sorption of radionuclides; inhibit the formation of particulates, colloids, inorganic complexes, or organic complexes that increase the mobility of radionuclides; or inhibit the transport of radionuclides by particulates, colloids, or complexes.	P	P	P	P	P
Favorable condition 4					
A combination of expected geochemical conditions and a volumetric flow rate of water in the host rock that would allow less than 0.001 percent per year of the total radionuclide inventory in the repository at 1,000 years to be dissolved.	P	P	P	P	P
Potentially adverse conditions 1					
Ground-water conditions in the host rock that could affect the solubility or the chemical reactivity of the engineered-barrier system to the extent that the expected repository performance could be compromised.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 2: GEOCHEMICAL CONDITIONS THAT WOULD INHIBIT RADIONUCLIDE TRANSPORT IN THE FAR FIELD					
Favorable condition 1					
The nature of rates of the geochemical processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years.	P	P	P	P	P
Favorable condition 2					
Geochemical conditions that promote the precipitation, diffusion into the rock matrix, or sorption of radionuclides; inhibit the formation of particulates, colloids, inorganic complexes, or organic complexes that increase the mobility of radionuclides; or inhibit the transport of radionuclides by particulates, colloids, or complexes.	P	P	P	P	P

Table 7-2. Guideline-condition findings by major consideration—geochemistry^{a,b} (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 2: GEOCHEMICAL CONDITIONS THAT WOULD INHIBIT RADIONUCLIDE TRANSPORT IN THE FAR FIELD (Continued)					
Favorable condition 5					
Any combination of geochemical and physical retardation processes that would decrease the predicted peak cumulative releases of radionuclides to the accessible environment by a factor of 10 as compared to those predicted on the basis of ground-water travel time without such retardation.	NP	NP	P	NP	P
Potentially adverse condition 3					
Pre-waste-emplacement ground-water conditions in the host rock that are chemically oxidizing.	NP	NP	NP	NP	P
MAJOR CONSIDERATION 3: GEOCHEMICAL EFFECTS ON THE SORPTIVE PROPERTIES AND ROCK STRENGTH OF HOST ROCK					
Favorable condition 3					
Mineral assemblages that, when subjected to expected repository conditions, would remain unaltered or would alter to mineral assemblages with equal or increased capability to retard radionuclide transport.	P	P	P	P	P
Potentially adverse condition 2					
Geochemical processes or conditions that could reduce the sorption of radionuclides or degrade the rock strength.	NP	NP	NP	NP	NP

^a Key: NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the condition is present at the site.

^b Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

potentially very corrosive to the stainless-steel container of the waste packages, but the small amount of water expected in the repository will limit waste-package degradation. The formation of some, but not all, colloids will be inhibited by the high salinity of brine. Because of their high concentrations in the brine, chlorides, sulfates, and carbonates could form complexes with radionuclides, which may increase the mobility of some radionuclides. While chemically reducing conditions are expected in the host rock and underlying aquifers, the ability of the water-rock system to maintain reducing conditions in the presence of alpha and gamma radiolysis may be limited.

The Hanford site may have a somewhat higher flow rate of water past the waste package than other sites. The bentonite and crushed-basalt packing material that will surround the low-carbon-steel disposal containers is expected to significantly reduce the flow rate of ground water that could come in contact with the waste. The ground water at Hanford has a low salinity in comparison with the salt sites and a high pH, which tends to reduce the rates of container corrosion. In addition, the chemically reducing conditions that are expected would lower the solubility of redox-sensitive radionuclides and further lower the rates of container corrosion. However, alpha and gamma radiolysis may result in localized oxidizing conditions around the disposal container. Ground water at the repository level contains carbonate and hydroxyl ions, which could complex with escaping radionuclides, thereby increasing their mobility. Interactions between the waste package and ground water may result in the precipitation of iron-silica that would tend to scavenge radionuclides. In addition, sorption is expected to play a major role in the retardation of radionuclide transport.

Richton Dome is probably driest of the salt sites because of the small quantity of brine inclusions typical of domed salt. The volumetric flow rate of ground water at the repository horizon from brine migration is expected to be extremely low. As a result, waste-package degradation should be limited in spite of the inherently corrosive nature of brine. The formation of some, but not all, colloids should be inhibited by the high salinity of brine. The chloride and sulfate present in the brine could form complex with, and thus increase the mobility of, some radionuclides. While chemically reducing conditions are expected in the host rock, the ability of the water-rock system to maintain reducing conditions in the presence of alpha and gamma radiolysis may be limited.

The Yucca Mountain site is in a geologic environment with a very low ground-water flux through the candidate repository horizon. The low salinity and the nearly-neutral pH of the ground water would tend to reduce the corrosion rate of the disposal container; however, the ground water is oxidizing and would tend to make the waste-package environment somewhat more corrosive than water with lower oxidation-reduction (redox) conditions. The potential for the formation of inorganic complexes in the ground water of the Yucca Mountain site is probably low because of the very low salinity of the water, although the carbonate present in the ground water may increase the mobility of some radionuclides. The nearly-neutral pH of the water is conducive to the low solubility of oxides and hydroxides of some radionuclides, especially the actinides. In addition, interactions between the waste package and ground water may result in the precipitation of iron-silica, which would tend to scavenge radionuclides.

Radionuclide transport. This major consideration relates directly to the qualifying condition with respect to the natural barriers that would inhibit the transport of radionuclides into the accessible environment; it is based on the first, second, and fifth favorable conditions and the third potentially adverse condition. The contributing factors that are the most important for the quantitative evaluation of radionuclide transport and retardation include sorption and precipitation as well as redox conditions. A summary of the evaluation for each site follows.

At the Davis Canyon site, the geochemical processes within the host rock are not expected to be altered by anything other than the dissolution of the host salt, and available data suggest that dissolution will not be a problem at Davis Canyon. The salt contains very small amounts of clay minerals that could enhance the sorption of migrating radionuclides. Conversely, the high ionic strength of the brine would tend to decrease the sorptive capacity of these clays. Redox conditions in the interbeds within the salt cycles and in the aquifer beneath the salt of the Paradox Formation are reducing, which decreases the solubility of some key redox-sensitive radionuclides. However, the chloride and carbonate, which are present in the brines in high concentration, could form complexes with radionuclides, and this may increase the mobility of these radionuclides. However, sulfate solubility relationships may limit the concentrations of some radionuclides.

At the Deaf Smith site, geochemical processes would not be expected to be altered by anything other than the dissolution of the host salt, and dissolution is not expected to be a problem at the site. The salt of the Deaf Smith site contains numerous mudstone inclusions and interbeds, and approximately half of them are composed of clay and clay-sized particles. Although it is possible that the clay could increase the sorption of migrating radionuclides, the high ionic strength of the brine tends to decrease the sorptive capacity of the clay. Ground water in the aquifer that underlies the salt cycles of the Palo Duro Basin is reducing, which further decreases the solubility of some key redox-sensitive radionuclides. However, the chloride and carbonate present in the brine could form complexes with radionuclides, thereby increasing their mobility. However, sulfate solubility relationships may limit the concentrations of some radionuclides.

At the Hanford site, little change is expected in the geochemical processes within the basalts because of the depth and the saturation of the repository horizon. The dense interior of the host rock should afford some degree of physical retardation for radionuclides. The geochemical environment of the site is favorable for the precipitation and sorption of radionuclides (i.e., reducing ground water and abundant secondary clays and zeolites from lining fracture and fragment surfaces). The secondary mineral assemblages that would be formed are believed to be stable under the temperatures expected in the disturbed zone. Since the data on colloids, particulates, and organics are limited, these factors cannot be fully evaluated at present. The ground water is of low salinity, but it contains carbonate and hydroxyl ions that could form complexes with radionuclides.

At the Richton site, the geochemical processes within the host rock would not be expected to be altered by anything other than dissolution. Available data suggest that dissolution should not be a problem at the site. The salt of the Richton Dome is predominantly halite with a very low water content.

Available data suggest that the water contained in fluid inclusions in the salt is reducing and should decrease the solubility of some redox-sensitive radionuclides. Because of their high concentrations, the chloride, sulfate, and carbonate present in the brines could form complexes with radionuclides, thereby increasing their mobility. However, sulfate solubility relationships may limit the concentration of some radionuclides.

At Yucca Mountain, little water is expected to pass through the tuff. The predominant mode of water migration is currently thought to be matrix flow along much of the ground-water-flow path. Sorption and diffusion are expected to delay or retard the migration of radionuclides. The oxidizing nature of the water may inhibit radionuclide precipitation and sorption for redox-sensitive radionuclides. The abundance of highly sorptive secondary clays and zeolites along ground-water-flow paths should provide a sorptive barrier to most radionuclides. Redox-sensitive radionuclides like technetium may not be retarded by sorption. The low salinity of the ground water would be conducive to the formation of some colloids since certain actinides form colloids in dilute nearly-neutral waters. Since the data on colloids, particulates, and organics are limited, these factors, cannot be fully evaluated at present.

Sorption and rock strength. This consideration addresses geochemical processes that could adversely affect the sorptive capacity or strength of the host rock, or both. The consideration relates directly to the qualifying condition with respect to the retardation of radionuclides by natural barriers in the repository and along ground-water-flow paths to the accessible environment; it is derived from the third favorable condition and the second potentially adverse condition. Sorption and rock strength are considered less important than the preceding considerations because they would affect only a small percentage of the total rock mass surrounding the repository. Change in the sorptive capacity of the host rock minerals is the most important contributing factor under this consideration because of the potential effect on the retardation of radionuclides. The major contributing factors for this consideration are the stability of mineral assemblages, the effects of mineral alteration on sorption, and the effects of mineral alteration on rock strength. A summary of the evaluation for each site follows.

The mineral assemblage at the Davis Canyon site may contain carnallite, which could dehydrate when subjected to repository heat and release magnesium-rich brines. High-magnesium brines would accelerate the degradation of the waste packages and subsequently lead to a release of radionuclides. In addition, alteration of the carnallite could reduce the strength of the host rock. However, the quantity of carnallite at the Davis Canyon site is expected to be small, and carnallite should have little effect on radionuclide containment.

The mineral assemblage at the Deaf Smith site includes interbeds and inclusions of mudstone. It is assumed that these consist of approximately 50 percent clay minerals that may dehydrate under the geochemical conditions within the repository. However, because of the small volume of clay minerals, the alteration of these materials is not expected to affect the retardation of radionuclides or the strength of the host rock.

The host rock at the Hanford site consists of basalt and a number of sorptive secondary minerals (e.g., clays, zeolites). Laboratory tests suggest that repository conditions may result in the formation of a mineral assemblage similar to the secondary minerals formed naturally in basalt as a result of hydrothermal alteration. Although the hydrothermal conditions near the repository could adversely affect the sorptive capacity of some of these minerals, there is abundant evidence that hydrothermal conditions could alter the volcanic materials to more sorptive materials (e.g., clays and zeolites). In general, the effects of the repository on rock strength are expected to be negligible.

At the Richton site, the mineral assemblage consists mainly of halite with some anhydrite. Because of the stability of the minerals at this site, it is expected that no geochemical alteration or reduction in rock strength would affect the transport of radionuclides.

The mineral assemblage in the host rock of the Yucca Mountain site consists of 98 percent quartz, feldspar, and cristobalite, with small amounts of secondary clays and zeolites. The sorptive capacity of the host rock is likely to be slightly reduced by the dehydration of clays and zeolites in the disturbed zone and remain unaffected in the surrounding rocks. Only very small amounts of volcanic glass are likely to be present. Rock strength is not expected to be affected by the geochemical conditions in the repository.

Summary of comparative evaluations

Hanford and Yucca Mountain are the most favorable sites for the geochemistry guideline. These two sites are expected to have the most favorable geochemical conditions with respect to the waste package and radionuclide retardation. The basalt at Hanford should respond favorably to geochemical conditions in the repository by creating additional sorptive capacity. Hanford also has more favorable redox conditions. Yucca Mountain has unsaturated conditions as well as the additional radionuclide-retardation effects of matrix diffusion.

The Davis Canyon, the Deaf Smith, and the Richton sites are favorable for all major considerations and are essentially equivalent with respect to the geochemistry guideline. They are less favorable than the nonsalt sites because the sorptive capacity of salt is very limited and the brines at these three sites could reduce the lifetime of the waste package. Moreover, the geochemical conditions in the salt sites are not expected to enhance the retardation of radionuclides through the alteration of the host rock to the degree that is expected at Hanford. The amount of brine, however, will probably be small, and the transport of radionuclides by this brine is likely to be quite limited. Therefore retardation due to geochemical effects may be of limited importance.

7.2.1.3 Rock characteristics (postclosure)

The qualifying condition for postclosure rock characteristics is as follows:

The present and expected characteristics of the host rock and surrounding units shall be capable of accommodating the thermal, chemical, mechanical, and radiation stresses expected to be induced by repository construction, operation, and closure and by expected interactions among the waste, host rock, ground water, and engineered components. The characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in §960.4-1 for radionuclide releases to the accessible environment and (2) the requirements set forth in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-3), three major considerations are identified that influence the favorability of the sites with respect to the qualifying condition. In order of decreasing importance, they are (1) the potential effects of repository-induced heat on waste containment or isolation, (2) the complexity of engineering measures required to ensure waste containment and isolation, and (3) flexibility for locating the underground facility to ensure waste isolation. These major considerations are, in turn, influenced by a number of more-specific rock properties and in situ conditions.

Evaluation of the sites in terms of the major considerations

Effects of repository-induced heat. This consideration is derived from the second favorable condition and second and third potentially adverse conditions. The factors contributing to this condition are the thermal properties of the host rock, such as thermal conductivity and the coefficient of thermal expansion; mechanical properties, such as a sufficiently high ductility for fractures to heal; thermomechanical behavior, such as the potential for thermally induced fractures; and geochemical conditions, such as the potential for brine migration and the hydration or dehydration of mineral components. This consideration also takes into account the effect of repository-induced heat on the integrity of the host rock and the surrounding rock units. Because of the potential effects of these factors on waste isolation, this major consideration is more important than the other two. A summary of the evaluation for each site follows.

At Davis Canyon, the effect of repository-induced temperature increases after closure can be favorable because of increases in the rate of salt creep, which would seal the underground openings and reconsolidate and recrystallize the salt backfill. Adverse impacts from a temperature increase would include the migration of brine within the host rock to the heat source and an increase in gas pressure if brines or gases are present in significant quantities. Limited site-specific data indicate very little brine is present at Davis Canyon. The adverse geochemical impacts from a temperature increase could also include mineral alteration and the dehydration of carnallite, but test

Table 7-3. Guideline-condition findings by major consideration—
rock characteristics (postclosure)^{a, b}

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: POTENTIAL IMPACT OF REPOSITORY-INDUCED HEAT ON WASTE CONTAINMENT OR ISOLATION					
Favorable condition 2					
A host rock with a high thermal conductivity, a low coefficient of thermal expansion, or sufficient ductility to seal fractures induced by repository construction, operation, or closure or by interactions among the waste, host rock, ground water, and engineered components.	P	P	P	P	P
Potentially adverse condition 2					
Potential for such phenomena as thermally induced fractures, the hydration or dehydration of mineral components, brine migration, or other physical, chemical, or radiation-related phenomena that could be expected to affect waste containment or isolation.	P	P	NP	P	NP
Potentially adverse condition 3					
A combination of geologic structure, structure, geochemical and thermal properties, and hydrologic conditions in the host rock and surrounding units such that the heat generated by the waste could significantly decrease the isolation provided by the host rock as compared with pre-waste-emplacement conditions.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 2: COMPLEXITY OF ENGINEERING MEASURES REQUIRED TO ENSURE WASTE CONTAINMENT AND ISOLATION					
Potentially adverse condition 1					
Rock conditions that could require engineering measures beyond reasonably available technology for the construction, operation, and closure of the repository, if such measures are necessary to ensure waste containment or isolation.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 3: SIGNIFICANT FLEXIBILITY IN HOST-ROCK DIMENSIONS TO ENSURE ISOLATION					
Favorable condition 1					
A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the underground facility to ensure isolation.	P	NP	NP	P	NP

^a Key: NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the condition is present at the site.

^b Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

results to date indicate that impacts from alteration or dehydration are not significant if the carnallite is under confining pressure.

At the Deaf Smith site, repository-induced temperature increases in the salt would contribute to creep effects like those at Davis Canyon. The rate of salt creep is expected to be higher at the Deaf Smith site than at Davis Canyon. The potential for creep-related disturbances to the interbeds and aquifers above the repository adds complexity at the Deaf Smith site.

At the Hanford site, repository-induced temperature increases may alter the permeability of the rock mass, through changes in fractures. It will also increase the in situ stresses in the vicinity of the excavations, possibly resulting in a readjustment of the rock mass and alterations in the local hydrologic regime. The rates of hydrochemical reactions among the various components will increase with the addition of heat. This is expected to have a positive effect on the isolation capabilities of the Hanford site.

At the Richton site, the effect of the repository-induced temperature increase on salt creep is expected to enhance the isolation capability of the site. The rate of salt creep at the Richton Dome is expected to be similar to that at the Deaf Smith site. The absence of stratification and the higher purity of the salt at Richton Dome should result in a less-anisotropic mechanical response to the temperature increase. The Richton Dome has a low brine content, and therefore minimal effects from brine migration are expected. Thermally induced uplift could affect the caprock (gypsum) over the dome, but modeling results indicate that such uplift is not expected to adversely affect the isolation capability of this site.

At Yucca Mountain, the problems associated with repository-induced heat are negligible, primarily because the underground facilities are in the unsaturated zone. The thermal pulse will modify the permeability of existing fractures since thermal expansion decreases the permeability of the rock mass, which in turn reduces the potential for new fractures. The Yucca Mountain site has some rock-mass heterogeneities that could cause an undetermined, but probably not adverse, response to heat (from both the variability of the content of lithophysae and the regions in which the tuff has been welded to different degrees). Although only preliminary measurements from surrounding strata are available, the rock stresses are not expected to be increased to unacceptable levels by the thermal response.

Complexity of engineering measures. This consideration includes in situ characteristics and conditions that could require engineering measures beyond reasonably available technology to ensure waste containment and isolation. Engineering measures relate directly to the qualifying condition through the specification that reasonably available technology is to be used to meet the requirements of the engineered-barrier system. It is derived from the first potentially adverse condition. The major contributing factors to this consideration are the uncertainty about the durability of man-made sealing material after closure and the effects of the in situ environment on engineered-barrier performance (e.g., the effects of brine on the disposal container). Complexity of engineering methods is considered less important than repository-induced heat effects because of the greater potential of heat effects to impair the isolation capabilities of the site. A summary of the evaluation for each site follows.

The sealing of boreholes and shafts at Davis Canyon is not expected to require complex engineering methods. The processes of sealing a repository in salt can be accomplished with technology developed in the salt-mining industry. With regard to interactions between the waste and the host rock, brines at Davis Canyon, if present, could accelerate the corrosion of the waste package.

Like Davis Canyon, the Deaf Smith site is not expected to require complex engineering methods. The site is expected to require particularly careful sealing to isolate the shaft from the Ogallala aquifer. The repository can be sealed by technology developed in the salt-mining industry from experience in drilling in the Palo Duro Basin. Interactions between the brine that may be present and the waste packages could accelerate the corrosion of the waste package, which could diminish the containment capabilities of the engineered-barrier system.

The ability to properly seal shafts and boreholes in basalt and to confirm the long-term effectiveness of seals are major concerns at Hanford. In particular, the sealing of the overlying aquifers from the repository horizon will require additional engineering measures to effectively isolate the waste. With regard to interactions of the various components of the engineered-barrier system, the expected presence of a geochemically reducing environment after closure and the sorptive properties of the secondary minerals formed in fractures in basalt are likely to enhance the containment and isolation capability at Hanford.

At the Richton site, shafts through the overlying saturated sediments and the caprock can be sealed by using technology similar to that used in mines in other salt domes. The sealing of the repository is not expected to require complex engineering measures. Interactions between the brine that may be present in the Richton Dome and the waste package could accelerate the corrosion of the waste package, which could diminish the containment capabilities of the engineered-barrier system.

At Yucca Mountain, the host rock is unsaturated; furthermore, construction experience at the Nevada Test Site shows that technology for borehole and shaft seals is readily available. In addition, since the seals will be required to perform only as well as the overall rock-mass permeability, long-term seal performance requirements are not particularly demanding. With regard to the interactions of the various components of the engineered-barrier system, the expected rock and geochemical conditions are favorable.

Flexibility. This consideration pertains to flexibility in determining the depth, configuration, and location of the underground repository. It relates to the qualifying condition because flexibility in locating the repository at a site increases the favorability of the site with respect to the qualifying condition. Added flexibility in locating the repository will help avoid geologic features or anomalies that could adversely affect the isolation capabilities of the site. Even after requirements for preclosure flexibility have been satisfied, added flexibility may still be necessary to satisfy this postclosure consideration in terms of the depth of excavations, the orientations of drifts and their intersections, and the location of

seals. A greater volume of host rock could provide isolation capability over and above the degree deemed minimally acceptable. On this basis, the contribution of flexibility to waste isolation is less than that of the other two considerations for this guideline. A summary of the evaluation for each site follows.

The host rock at Davis Canyon is expected to offer significant flexibility in that the available thickness appears to be several times greater than the required thickness. In addition, the potential host rock extends laterally underground for many kilometers. The presence of significant interbeds, impurities, gases, and structural features and their potential for adverse effects on flexibility are not yet well defined at this site.

At the Deaf Smith site, numerous interbeds may limit the vertical flexibility of locating a repository with respect to isolation considerations. In contrast, the host rock is expected to extend laterally for a considerable distance. The presence of impurities, brines, gases, and structural features and their potential to adversely affect flexibility are not yet well defined.

The Hanford site appears to offer restricted vertical but extensive horizontal flexibility with respect to isolation considerations. The thickness of the basalt can vary significantly over short distances, and the predictability of host-rock thickness is considered to be uncertain because of a limited data base.

The Richton site provides significant vertical flexibility and adequate lateral flexibility. Unfavorable internal structures within the salt dome could be encountered during site characterization; if present, they would diminish the flexibility for locating underground facilities at this site.

The host rock at Yucca Mountain offers significant vertical flexibility, but lateral flexibility is restricted by minor faults, shallow overburden, or site anomalies. The lateral homogeneity of the potential host rock outside the primary repository area has not been established.

Summary of comparative evaluation

Yucca Mountain is the most favorable site on the basis of the two most important considerations. It is expected that the response of the host rock to the heat loading of the repository would have an overall favorable effect. Furthermore, the long-term seal-performance requirements at Yucca Mountain are not expected to be very demanding. Although the flexibility for locating the underground facility is limited at Yucca Mountain, this does not outweigh the favorability of the other more important considerations.

The Davis Canyon and the Richton sites are next in favorability for the rock-characteristics guideline. At Davis Canyon, the repository-induced temperature increase is expected to improve the performance of the site by increasing the rate of salt creep, which would seal the underground openings by reconsolidating the salt backfill. However, the impact of the brine migration toward the heat source needs to be assessed. The sealing of

boreholes and shafts at Davis Canyon is not expected to require complex engineering methods. Davis Canyon is also expected to offer significant flexibility in locating the repository because of its lower brine content. The Richton site is more favorable than Davis Canyon for the repository-induced heat consideration. Richton is less favorable than Davis Canyon and Yucca Mountain on the basis of the major consideration for the complexity of engineering methods because of potential problems with sealing the repository from the overlying sediments and caprock. The Davis Canyon and the Richton sites are equally favorable with respect to host-rock flexibility. On the basis of these comparisons, Davis Canyon and Richton are approximately equal in favorability under this guideline.

Hanford is somewhat less favorable than the Yucca Mountain, the Davis Canyon, and the Richton sites for this guideline. Although Hanford is very favorable with respect to the effects of repository-induced heat, it may require complex engineering methods because of potential difficulties in sealing the overlying aquifers from the repository horizon. There has been little experience in sealing hard-rock mines to the degree that will be required for the repository. Hanford also appears to offer restricted vertical flexibility with respect to isolation considerations.

The Deaf Smith site is considered to be somewhat less favorable with regard to the rock-characteristics guideline. It is the least favorable site for the major consideration of repository-induced heat because of more-extensive interbeds. It is also the least favorable site under the third major consideration because the presence of interbeds limits its vertical flexibility. However, these considerations are not likely to significantly affect the ability of the site to contain or isolate waste.

7.2.1.4 Climatic changes

The qualifying condition for the climatic changes guideline is as follows:

The site shall be located where future climatic conditions will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in §960.4-1. In predicting the likely future climatic conditions at a site, the DOE will consider the global, regional, and site climatic patterns during the Quaternary Period, considering the geomorphic evidence of the climatic conditions in the geologic setting.

Major consideration

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-4), one major consideration is identified that influences the favorability of the sites with respect to the qualifying condition: the effect of future climatic changes on the ability of the site to isolate waste. Contributing factors include Quaternary climatic cycles and the in situ conditions at a site. The major consideration is directly related to the qualifying condition through the consideration of

Table 7-4. Guideline-condition findings by major consideration—climatic change^{a, b}

Condition ^c	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
Favorable condition 1					
A surface-water system such that expected climatic cycles over the next 100,000 years would not adversely affect waste isolation.	P	P	P	P	P
Favorable condition 2					
A geologic setting in which climatic changes have had little effect on the hydrologic system throughout the Quaternary Period.	NP	NP	NP	NP	NP
Potentially adverse condition 1					
Evidence that the water table could rise sufficiently over the next 10,000 years to saturate the underground facility in a previously unsaturated host rock.	NA	NA	NA	NA	NP
Potentially adverse condition 2					
Evidence that climatic changes over the next 10,000 years could cause perturbations in the hydraulic gradient, the hydraulic conductivity, the effective porosity, or the ground-water flux through the host rock and the surrounding geohydrologic units, sufficient to significantly increase the transport of radionuclides to the accessible environment.	NP	NP	NP	NP	NP

^a Key: NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the condition is present at the site.

^b Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

^c All the conditions in this table are associated with one major consideration: the effect of climatic changes on the ability of the site to isolate the waste.

climatic changes that may affect waste isolation. It is derived from the two favorable conditions and the two potentially adverse conditions. A summary of the evaluation for each site follows.

Evaluation of sites with respect to the major consideration

At the Davis Canyon site, climatic changes during the Quaternary Period are thought to have increased precipitation by as much as 120 percent. Increased precipitation during the Pleistocene may have increased recharge rates and flow through hydrostratigraphic units as well as rates of erosion and dissolution. Estimates of increased precipitation are based on regional data that cover the last 13,000 years and site-specific geomorphic data. Although it is uncertain by how much increased precipitation affected the hydrologic system, it does not appear that changes of the same magnitude would adversely affect waste isolation. To establish bounding cases for the potential effects of increased precipitation on the hydrologic system, a simple worst-case assumption was made in which increased precipitation raises the water table to the ground surface in the Abajo Mountains. The resulting hydraulic gradient between the Abajo Mountains and the Colorado River is not significantly greater than the present maximum apparent hydraulic gradient estimated from hydrologic tests. Preliminary estimates of the rates of erosion and dissolution during the Quaternary Period, if projected into the future, would not affect the isolation capability of the host rock, because no significant changes in flow parameters, such as porosity or permeability, have been identified in the Quaternary Period. Preliminary estimates of the maximum rates of incision over the next 100,000 years are approximately 40 meters (132 feet). Although increased rates of incision may alter the surface-water system, increased incision at the surface is not expected to affect the integrity of a repository at a depth of 885 meters (2,900 feet).

At the Deaf Smith site, regional data indicate that lower temperatures and increased effective moisture occurred during the Pleistocene. The Quaternary record suggests cyclical increases in precipitation during pluvial cycles. Increases in precipitation during future pluvial conditions would increase surface-water ponding and growth of vegetation. The increased vegetation would tend to decrease the rates of erosion, though localized increases in erosion could occur near escarpments. Although these climatic changes would change the surface-water system, they are not expected to reduce the waste-isolation capabilities of the host rock. Potential effects of Quaternary climatic cycles on the hydrologic system include changes in the rates of recharge and increased rates of dissolution at salt margins. Increased recharge to the upper hydrostratigraphic unit would result in an increase in the hydrologic gradient between this unit and the underlying units, but models of this process show no significant effect in the underlying units for more than 10,000 years. Although the data are insufficient to quantify the effects of these changes on the hydrologic system, there is no evidence to suggest that Quaternary climatic changes had a significant effect on the ground-water system.

At the Hanford site, if glacially induced catastrophic floods recurred, they would alter the present surface-water system by increasing runoff, the rates of erosion, and ponding. The net effect of catastrophic flooding would be sediment aggradation. These changes in the surface-water system would be short-lived and are not expected to significantly affect the confined aquifers

of the Grande Ronde basalts. If glaciation were to recur, the major adverse effects would be increased recharge from meltwater and catastrophic flooding. Increased recharge may be expected to cause some rise in the potentiometric surfaces of shallow aquifer systems, but the transient nature of increased recharge is such that significant long-term effects on the confined aquifers of the Grande Ronde basalts are not expected.

For the Richton site, the data are insufficient to quantify the effects of future climatic changes on the surface-water system. However, regional data suggest that, if the climate returned to a glacial maximum, increased precipitation would slightly increase erosion and ground-water recharge. During the late Wisconsinian glaciation, the sea level in the Gulf of Mexico was 100 to 130 meters (330 to 430 feet) below the present mean sea level. This regional change in base level, combined with regional uplift, resulted in stream entrenchment. Geomorphic evidence in the region suggests that stream entrenchment in major rivers was on the order of 30 meters (100 feet). This would have little effect on the deep confined ground-water system around the Richton Dome. A future interglacial cycle accompanied by a melting of the ice sheets equivalent to Pleistocene interglacials could cause a rise in sea level of 5 to 10 meters (16 to 32 feet). An equivalent rise in sea level would not inundate the surface of the site, which is at least 50 meters (164 feet) above the mean sea level. Thus, the analysis of regional data suggests that future climatic changes would not affect the surface-water or the ground-water systems to the extent that the isolation capabilities of the site would be affected.

Analysis of data on the effects of climate changes in the vicinity of Yucca Mountain suggests that surface-water systems changed little during the Quaternary Period and are not expected to change significantly in the next 10,000 years. The present surface-water system was established by early Quaternary time. It is unlikely that the maximum probable climatic change, from arid to semiarid conditions, would cause a significant change in the present drainage system. Climatic data suggest that Quaternary climatic changes had the following effects on the ground-water system: increased recharge; increased elevation of, and gradients in, the water table; and upgrade shifts in discharge points. Data from the region suggest that the effects of these changes were minor. One exception may be the effect of increased recharge on the hydrologic system, though the magnitude of the increased recharge has not yet been quantified.

If pluvial conditions were to occur, increased recharge may have a significant effect on the ground-water flux and may raise the level of the water table. Preliminary modeling of increases in the water table during a full pluvial cycle, assuming a 100-percent increase in precipitation, suggests a maximum rise of 130 meters (427 feet). Such a rise in the water table would not saturate the repository. Furthermore, considering the various sources of uncertainty in the model--such as the method used to simulate recharge, the assumption that the response of the water table is instantaneous, and the use of a two-dimensional model to simulate three-dimensional flow--the prediction of a 130-meter rise in the water table is uncertain and may not be realistic. It is unlikely that increased recharge from a return to pluvial conditions would significantly increase radionuclide transport to the assessable environment.

Summary of the comparative evaluation

The available data suggest that the Davis Canyon, Deaf Smith, Hanford, and Richton sites are equally favorable with respect to the major consideration and the guideline on climatic changes. At these sites changes in the surface-water system over the next 100,000 years are not expected to adversely affect isolation capabilities. Climatic changes during the Quaternary Period may have had minor effects on the ground-water systems. In the next 10,000 years, none of these sites is expected to undergo climatic changes that would decrease the ability of the natural barriers to isolate the waste.

The Yucca Mountain site is less favorable than the other sites because future climatic changes may produce a significant increase in recharge to the geohydrologic system. Assuming an eventual return to pluvial conditions, preliminary modeling suggests that increased recharge may increase the ground-water flux, decrease the ground-water travel time, and increase the elevation of the water table. The potentially increased flux, combined with a substantial rise in the water table, introduces greater uncertainty in assessing the potential effects of future climatic changes on the Yucca Mountain site. However, climatic conditions during the next 10,000 years would not be likely to significantly increase radionuclide releases to the accessible environment.

7.2.1.5 Erosion

The qualifying condition for erosion is as follows:

The site shall allow the underground facility to be placed at a depth such that erosional processes acting upon the surface will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in §960.4-1. In predicting the likelihood of potentially disruptive erosional processes the DOE will consider the climatic, tectonic, and geomorphic evidence of rates and patterns of erosion in the geologic setting during the Quaternary Period.

Major consideration

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-5), one major consideration is identified that influences the favorability of the sites with respect to the qualifying condition: the effects of erosional processes on waste isolation. The major consideration is derived from the three favorable conditions and the two potentially adverse conditions and evaluates effects of erosional processes on waste isolation. It is directly related to the qualifying condition through emphasis on the ability to isolate waste.

Table 7-5. Guideline-condition findings by major consideration—erosion^{a, b}

Condition ^c	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
Favorable condition 1					
Site conditions that permit the emplacement of waste at a depth of least 300 meters (984 feet) below the directly overlying ground surface.	P	P	P	P	NP
Favorable condition 2					
A geologic setting where the nature and rates of the erosional processes that have been operating during the Quaternary Period are predicted to have less than 1 chance in 10,000 over the next 10,000 years of leading to releases of radionuclides to the accessible environment.	P	P	P	P	P
Favorable condition 3					
Site conditions such that waste exhumation would not be expected to occur during the first 1 million years after repository closure.	P	P	P	P	P
Potentially adverse condition 1					
A geologic setting that shows evidence of extreme erosion during the Quaternary Period.	NP	NP	NP	NP	NP
Potentially adverse condition 2					
A geologic setting where the nature and rates of geomorphic processes that have been operating during the Quaternary Period could, during the first 10,000 years after closure, adversely affect the ability of the geologic repository to isolate the waste.	NP	NP	NP	NP	NP

^a Key: NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the condition is present at the site.

^b Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

^c All of the conditions in this table are associated with one major consideration: effects of erosional processes on waste isolation.

Contributing factors include the depth of waste emplacement, evidence of extreme erosion during the Quaternary Period, the potential for uncovering the waste, and the assessment of future erosion rates and geomorphic processes on the basis of the climatic, tectonic, and geomorphic evidence of erosion rates and patterns during the Quaternary Period. These factors cannot be evaluated individually to make a judgment on the qualifying condition; they must be evaluated together. It is for this reason that only one major consideration is identified. A summary of the evaluation for each site follows.

Evaluation of sites in terms of the major consideration

At Davis Canyon, the host-rock unit (salt cycle 6) is estimated to occur at a depth of approximately 885 meters (2,900 feet). During the Quaternary Period, erosion in the candidate area has been almost continuous, though long-term rates of incision are not thought to be extreme. Stream erosion is predicted to erode no more than approximately 3 meters (12 feet) below the present ground surface in 10,000 years. Streams in the region have been predicted to erode up to 240 meters (800 feet) into their present channels (using long-term incision rates) during the first million years after repository closure. The Quaternary geologic record indicates that geomorphic processes should not adversely affect the ability of the repository to isolate the waste. This includes a preliminary assessment of the eastward propagation of the graben systems west of the site. Considering the planned depth of the repository, present knowledge suggests that it is highly unlikely that erosion will lead to releases of radionuclides to the accessible environment in the next 10,000 years.

At the Deaf Smith site, the host rock is in Unit 4 of the Lower San Andres Formation, where the top of the unit is 700 to 760 meters (2,300 to 2,500 feet) below the surface. No evidence is recorded of extreme erosion at the site. Extrapolation from a relatively high river-incision rate in Holocene time shows erosion to a depth of 63 meters (210 feet) in the next 10,000 years. Projections of average Quaternary conditions indicate that erosion of 100 meters (330 feet) would occur over the next 1 million years. Projections of Quaternary erosional conditions indicate that the waste would remain isolated after 10,000 years. Considering the planned depth of the repository, it is unlikely that erosion will lead to releases of radionuclides to the accessible environment in the next 10,000 years.

At the Hanford site, the depth to the Cohasset flow top is 869 to 943 meters (2,850 to 3,093 feet). The site does not show evidence of extreme erosion during the Quaternary Period. Because the depth of erosion is geomorphically controlled by base level, future incision is limited to depths above the minimum sea level. Past glacially induced sea-level changes indicate that erosion at the site could proceed no further than about 440 meters (1,443 feet) above the top of the candidate horizon. The depth of the candidate horizon and the geologic setting of the site are such that the waste would not be expected to be uncovered during the first million years after repository closure. There is little chance, if any, of erosion leading to a release of radionuclides to the accessible environment over the next 10,000 years.

At the Richton site, the waste would be emplaced at a depth of 646 meters (2,119 feet). No evidence of sustained extreme erosion during the Quaternary Period is found in the geologic setting of the site. The geomorphic processes that have been in operation during the Quaternary Period have resulted in a long-term erosion rate of 1.2 meters (4 feet) per 10,000 years. This rate would result in the removal of 120 meters (394 feet) of material in 1 million years, leaving 526 meters (1,718 feet) of material over the repository. The chance of erosion removing the entire thickness of overdome sediments is much less than 1 in 1 million. Thus, it is very unlikely that erosion over the next 10,000 years would lead to any radionuclide releases to the accessible environment.

At Yucca Mountain, the minimum thickness of the overburden above the repository would be about 230 meters (750 feet). For about 50 percent of Yucca Mountain, the overburden is more than 300 meters (984 feet). Average stream-incision rates during the past 300,000 years have not been extreme, and there has been little change in the patterns of erosion at the site during the Quaternary Period. On the basis of average stream-incision rates, the shallowest portion of the repository is expected to remain buried much longer than 1 million years. Over a period of 10,000 years, erosional processes would be expected to remove only 1 meter (3 feet) of overburden. The probability that erosion would induce a loss of isolation is less than 1 in 1 million over the next 10,000 years. Thus, although the Yucca Mountain site does not meet the favorable condition on the depth of emplacement, it appears that the probabilities of erosion causing a loss of isolation are lower than those considered credible in EPA regulations (40 CFR Part 191).

Summary of the comparative evaluation

At all the sites, the underground repository can be placed deep enough to protect it from erosional processes acting on the surface. The predicted rates of erosion are low at all five sites. All waste-emplacement horizons are too deep for credible geomorphic processes to adversely affect the performance of the repository. Although the rates of erosion vary from site to site, the variation is not significant. None of the sites is expected to erode to such an extent that the waste would be uncovered during the first 1 million years. It is also very unlikely that erosion at any of the sites would result in releases of radionuclides during the first 10,000 years. Therefore, all sites are approximately equivalent with respect to the erosion guideline.

7.2.1.6 Dissolution:

The qualifying condition for postclosure dissolution is as follows:

The site shall be located such that any subsurface rock dissolution will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in §960.4-1. In predicting the likelihood of dissolution within the geologic setting at a site, the DOE will consider the evidence of dissolution

within that setting during the Quaternary Period, including the locations and characteristics of dissolution fronts or other dissolution features, if identified.

Major consideration

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-6), one major consideration is identified that influences the favorability of the sites with respect to the qualifying condition: evidence of host-rock dissolution during the Quaternary Period. This major consideration is influenced by several contributing factors, such as the solubility of the host rock under nonextreme geologic and hydrologic conditions, unusual ground-water chemistry, and evidence of significant dissolution during the Quaternary Period. The consideration is directly related to the qualifying condition through concern about the disruption of the natural and engineered barriers by the dissolution of the host rock. Such disruption would result in the potential for exceeding the radionuclide-release limits set by the NRC and the EPA. A summary of the evaluation for each site follows.

Evaluation of sites in terms of the major consideration

The Davis Canyon site is 16 kilometers (10 miles) from the nearest known or potential dissolution feature. Although data on the rate of migration of dissolution fronts in the Paradox Basin are not available, the rates estimated for other basins suggest that a dissolution front would not reach the site for at least 10,000 years. However, it should be noted that the use of such an extrapolation technique increases the level of uncertainty in this estimate. Other known and suspected dissolution features in the area include the Lockhart Basin, 19 kilometers (12 miles) to the north; Beef Basin, 22 kilometers (14 miles) to the southwest; the Needles Fault Zone, 18 kilometers (11 miles) to the west; and the Shay/Bridger Jack/Salt Creek graben system, 16 kilometers (10 miles) to the south. Data derived from field mapping and geophysical logging near the site have not revealed features that would indicate Quaternary dissolution. However, the saline ground waters of the overlying Honaker Trail Formation and the underlying Leadville Formation are thought to indicate past or continuing dissolution of the salt in the Paradox Formation.

The Deaf Smith site is somewhat further from active dissolution fronts than Davis Canyon. Dissolution at or above the repository level is known to occur 103 kilometers (64 miles) to the west, 29.8 kilometers (18.5 miles) to the north and 118 kilometers (73 miles) to the east of the Deaf Smith site. The rates of migration for these dissolution fronts have been calculated from data on the level of salinity in streams. These data suggest that the most rapid rate of migration for the dissolution fronts is 0.98 meter (3.2 feet) per year for the eastern front, while the northern front is migrating at a rate of 0.0008 meter (0.0024 foot) per year. The rate of dissolution for the western front is expected to be even lower. These calculations are based on the assumption that the dissolution front is uniform, which could underestimate the actual rate of dissolution. Within the basin, interior dissolution is evident in the uppermost salt sequence beneath the High Plains aquifer, as indicated by data from dissolution wells. However, the rate of

Table 7-6. Guideline-condition findings by major consideration--dissolution^{a, b}

Condition ^c	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
Favorable condition					
No evidence that the host rock within the site was subject to significant dissolution during the Quaternary Period.	P	P	P	P	P
Potentially adverse condition					
Evidence of dissolution within the geologic setting--such as breccia pipes, dissolution cavities, significant volumetric reduction of the host rock or surrounding strata, or any structural collapse--such that a hydraulic interconnection leading to a loss of waste isolation could occur.	P	P	NP	P	NP

^a Key: NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the condition is present at the site.

^b Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

^c All of the conditions in this table are associated with one major consideration: effects of dissolution processes on waste isolation.

dissolution is very slow and has been estimated to be 0.000064 meter (0.000021 foot) per year. No dissolution fronts near the Deaf Smith site or in the interior basin are expected to intersect the repository horizon in less than 100,000 years.

The rock at the Hanford site consists of minerals that are not readily soluble, and significant dissolution leading to radionuclide releases from the site is not considered credible. It is highly unlikely that dissolution will occur along fractures within the repository during or after the thermal phase to the extent that the permeability of the fracture system will increase. The permeability of the fracture system will probably decrease because of the alteration of glass and the formation of clays and zeolites within the fractures.

The Richton site has no topographic depressions over the salt dome, and limited data suggest that the Tertiary sediments overlying the dome are laterally continuous. There are two relatively small, closed circular depressions just off the eastern flank of the dome that appear to be the result of near-surface processes; however, at this time, their origin is uncertain. Samples of ground water from a shallow fresh-water aquifer reveal possible saline anomalies on the south side of the dome (downgradient of the dome). These anomalies were identified on the basis of a very limited number of boreholes; therefore, the origin of the high salinity level in the water of the upper aquifer is unknown at this time. Possible origins for the salinities include salt-dome dissolution, variability of aquifer conditions, and artificial contamination.

The Yucca Mountain site is composed of rock whose minerals are not readily soluble, and significant dissolution leading to radionuclide releases from the site is not considered credible. It is highly unlikely that dissolution will occur along fractures within the repository during or after the thermal phase to the extent that the permeability of the fracture system will increase.

Summary of comparative evaluation

Hanford and Yucca Mountain are the most favorable sites for the dissolution guideline because the host rocks and surrounding unit consist of minerals that are not readily soluble.

The Davis Canyon, Deaf Smith, and Richton sites are less favorable. Available data suggest that dissolution probably occurred at each salt site during the Quaternary Period, but the rates of dissolution are too low to lead to a loss of waste isolation. There is, however, considerable uncertainty associated with these rates because of the limited data base for each site.

7.2.1.7 Tectonics (postclosure)

The qualifying condition for postclosure tectonics is as follows:

The site shall be located in a geologic setting where future tectonic processes or events will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in §960.4-1. In predicting the likelihood of potentially disruptive tectonic processes or events, the DOE will consider the structural, stratigraphic, geophysical and seismic evidence for the nature and rates of tectonic processes and events in the geologic setting during the Quaternary Period.

Major consideration

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-7), one major consideration is identified that influences the favorability of the sites with respect to the qualifying condition. This major consideration concerns estimates and projections of igneous activity and tectonic processes over the next 10,000 years and the effect of these processes on radionuclide releases. It is directly related to the qualifying condition through the evaluation of radionuclide releases attributed to potential tectonic phenomena. It is derived from the favorable condition and the six potentially adverse conditions.

The contributing factors for this major consideration include evidence of tectonic or igneous activity during the Quaternary Period, the likelihood for the next 10,000 years of tectonic and igneous events that could alter the regional ground-water-flow system, the historical record of seismicity, the correlation of earthquakes with tectonic features, evidence of Quaternary tectonic processes (especially at the repository site), and the potential effects of tectonic and igneous events on the repository. The rates of igneous and tectonic activities cannot be evaluated individually; these conditions must be evaluated together to determine their impact on the total isolation system, and therefore only one major consideration was identified for this guideline. A summary of the evaluation for each site follows.

Evaluation of sites in terms of the major considerations

In the geologic setting of the Davis Canyon site, Quaternary uplift has averaged less than 0.60 meter (2 feet) per 1,000 years. Although no surface faults have been identified at the site, Quaternary faulting may be present in the vicinity of the site at Shay Graben. These faults, however, may be related to salt dissolution rather than tectonism. These faults do not trend toward the site, nor have preliminary investigations shown any surface faults at the site. No known igneous activity has occurred within the geologic setting in the last 2 to 3 million years. No earthquakes have been observed within the site, but the historical record of seismicity is limited. The Paradox Basin has been classified as a relatively low seismic hazard region. However, there is a possibility that the south Shay Graben fault may be capable of producing an earthquake larger than any observed in the geologic setting. The geologic record does not show that any natural impoundments on

Table 7-7. Guideline-condition findings by major consideration-tectonics (postclosure)^{a, b}

Condition ^c	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
Favorable condition 1					
The nature and rates of igneous activity and tectonic processes (such as uplift, subsidence, faulting, or folding), if any, operating within the geologic setting during the Quaternary Period would, if continued into the future, have less than 1 chance in 10,000 over the first 10,000 years after closure of leading to releases of radionuclides to the accessible environment.	P	P	P	P	NP
Potentially adverse condition 1					
Evidence of active folding, faulting, diapirism, uplift, subsidence, or other tectonic processes or igneous activity within the geologic setting during the Quaternary Period.	P	P	P	P	P
Potentially adverse condition 2					
Historical earthquakes within the geologic setting of such magnitude and intensity that, if they recurred, could affect waste containment or isolation.	NP	NP	NP	NP	NP
Potentially adverse condition 3					
Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or the magnitude of earthquakes within the geologic setting may increase.	P	NP	P	NP	P
Potentially adverse condition 4					
More-frequent occurrences of earthquakes or earthquakes of higher magnitude than are representative of the region in which the geologic setting is located.	NP	NP	NP	NP	NP
Potentially adverse condition 5					
Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such magnitudes that they could create large-scale surface-water impoundments that could change the regional ground-water flow system.	NP	NP	NP	NP	NP
Potentially adverse condition 6					
Potential for tectonic deformations—such as uplift, subsidence, folding, or faulting—that could adversely affect the regional ground-water flow system.	NP	NP	NP	NP	NP

^a Key: NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the condition is present at the site.

^b Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

^c All of the conditions in this table are associated with one major consideration: nature and rates of tectonic processes and igneous activity that may affect waste isolation.

the scale necessary to cause large changes in the regional ground-water-flow system occurred in the geologic setting. Regional uplift will not affect the physical integrity of the repository and will be too small to significantly modify ground-water-flow systems in the next 10,000 years. Reactivation of the basement faults beneath the site is possible, but it is doubtful that displacements large enough to propagate these features through the ductile rocks of the Paradox Formation would occur in the next 10,000 years. In general, tectonic data indicate that the likelihood of disruptive tectonic events is very low and suggest that igneous or tectonic activity at the Davis Canyon site could not lead to radionuclide releases greater than regulatory limits after repository closure.

At the Deaf Smith site, data were collected by reviewing published literature and conducting preliminary field surveys. There is no evidence of igneous activity during the Quaternary Period at the Deaf Smith site. The nearest igneous activity during the Quaternary occurred about 160 kilometers (99 miles) west of the site, outside the geologic setting. Quaternary tectonic processes were probably negligible near the site. Regional uplift or subsidence is not recognized, but the possibility that these processes occurred on a small scale during the Quaternary Period has not been ruled out. The site is located in a region of low seismicity. Quaternary faulting and folding of a tectonic (or seismogenic) nature are not recognized in the Palo Duro Basin. No large damaging earthquakes have occurred in the geologic setting during the period of the historical record. The terrain of the site and its vicinity is flat and would not be affected by natural phenomena large enough to cause large-scale surface-water impoundments. Small amounts of uplift or subsidence are not likely to adversely affect the regional ground-water flow over the next 10,000 years. Some uncertainty exists because site-specific information on subsurface faulting has yet to be fully evaluated. However, the likelihood of disruptive tectonic events affecting any releases of radionuclides after closure is thought to be extremely low.

For the Hanford site, preliminary estimates of the rates of tectonic deformation suggest low long-term average rates of strain. Volcanism in the Columbia River Basalt Group ceased approximately 6 million years ago. Although Quaternary volcanism has occurred in the western Columbia Plateau, it appears to be more closely related to volcanism in the Cascades. There are faults within the Columbia Plateau that are interpreted to have been active during the Quaternary Period. Seismic activity has been monitored at Hanford since 1969, but detailed seismic monitoring at the proposed repository depth is only beginning. Some of the faults in the geologic setting could be associated with earthquakes larger than the historical maximum. Available data do not permit the precise determination of slip and recurrence rates for specific faults; however, on the basis of current knowledge, earthquakes near the site would be relatively small, with long recurrence rates for larger events (a magnitude greater than about 5.5). Earthquakes are not currently associated with mapped geologic structures, nor do hypocenters align in a manner that suggests unmapped, buried, or steeply dipping faults occur in the Pasco Basin. It does not appear that natural phenomena or tectonic deformations would create large-scale surface-water impoundments that would cause significant changes in the regional ground-water-flow system.

Although the rate of deformation at Hanford does not appear to be significant enough to affect the release of radionuclides, there is

considerable uncertainty because microearthquake swarms have been observed in the basalt during the past 16 years, though no swarms have occurred recently in the basalt at the site. The potential effects of microearthquake swarms on system performance (including the ground-water-travel time, system geochemistry, and waste-package integrity) suggest that the likelihood of tectonic phenomena affecting the site's ability to isolate waste over the next 10,000 years is very low.

At the Richton site, the evidence from the geologic setting suggests that no igneous activity and only minor tectonic activity occurred during the Quaternary Period. The principal active tectonic process during the Quaternary Period is regional uplift. Diapirism does not appear to have occurred at the Richton Dome. There has been no igneous activity in or near the Mississippi salt basin since the Cretaceous Period (about 60 million years ago). There is no evidence of Quaternary seismogenic fault movement in the geologic setting, and the infrequent seismic activity that does occur is low in magnitude. The nearest known earthquake epicenter is 75 kilometers (45 miles) away. The region has no large surface-water impoundments from tectonic or igneous processes. Projections of uplift based on Quaternary data suggest that its rates are too low (0.01 meter per 1,000 years) to adversely affect the regional ground-water-flow system during the next 10,000 years. On the basis of the Quaternary record, future tectonic processes and events are not likely to be disruptive, and the likelihood of disruptive tectonic events is very low.

Much of the background data for the evaluation of tectonic activity at Yucca Mountain has been developed through many years of study related to nuclear weapons testing at the Nevada Test Site. The assessment of future tectonic processes is uncertain and difficult for Yucca Mountain. There is evidence that volcanism and faulting occurred in the vicinity of the site during the Quaternary Period. In addition, the seismicity of the region is not understood well enough to rule out the possibility of large earthquakes (magnitude of 7 or greater) occurring in the region after closure. According to previously published estimates of recurrence intervals, regional return periods for earthquakes with a magnitude of 7 or greater are probably on the order of 25,000 years. At present, a preliminary conclusion could be made that the north-trending faults at the site should be considered potentially active, even though the absence of fault scarps and the low level of seismic activity suggests they are not active. The geologic setting of Yucca Mountain is not yet well enough understood to preclude the possibility of future earthquakes larger than those that have occurred at or near the site.

The formation of large-scale surface-water impoundments by natural phenomena like landslides, subsidence, or volcanic activity is not likely in the area of Yucca Mountain. There is also a very small potential for tectonic deformation at the site of a magnitude that would affect the regional ground-water flow. On the basis of available information, it appears unlikely that volcanic events or future tectonic processes and events would adversely affect the containment and isolation capabilities of the repository, although numerical probabilities have not been determined for most processes. This conclusion is based on the moderate (although uncertain) probabilities of tectonic events, the likelihood that the ground-water travel time is long and the flux is low, the selection of waste-emplacement areas away from

recognizable fault zones, the structural integrity of the waste package, and the geochemical characteristics of the site.

Summary of comparative evaluation

The most favorable sites with respect to the postclosure tectonics guideline are Davis Canyon, Deaf Smith, and Richton. Although the Davis Canyon site appears to have a higher rate of tectonic activity near the site (as indicated by potential Quaternary faulting), there is a very low likelihood that tectonic events could lead to releases at any of these sites, and none show evidence of igneous activity in the geologic setting. Active faulting may also be present in the geologic setting of Davis Canyon, but no surface faults have been identified at the site, and seismic and geologic evidence qualitatively suggests that the region will be stable over the long term. The available data suggest that there is very little likelihood of disruptive tectonic or igneous events during the next 10,000 years at all three sites. Both the Deaf Smith and the Richton sites have experienced no igneous activity and insignificant tectonic activity during the Quaternary Period. There are no known Quaternary seismogenic faults in either geologic setting, and the level of seismicity at both sites appears to be very low.

Hanford is slightly less favorable than the salt sites for this guideline. There is some evidence that deformation is occurring within the basalts at Hanford, but the pattern of deformation qualitatively matches the pattern of known seismicity, suggesting that earthquakes and rupture planes would be relatively small and recurrence times generally long. There is some uncertainty because microearthquake swarms in the basalts have been observed during the past 16 years. In addition, no microearthquakes (nonswarm) have been observed within the repository site at the depth of the basalts. The likelihood of tectonic phenomena affecting the ability of the site to isolate waste over the next 10,000 years is very low.

Yucca Mountain is less favorable than the other sites. Quaternary faults are present within 1 to 6 kilometers of the site. Their effects on the potential for ground motion and on ground-water flow need to be assessed. The likelihood of volcanism may be high enough for volcanism to be considered in performance assessment. However, the effects of igneous and tectonic activity on system performance (qualifying condition) at Yucca Mountain are not expected to lead to radionuclide releases greater than those allowed by regulation. This assessment accounts for ground-water flux and travel time, waste emplacement away from recognized fault zones, the structural integrity of the waste package, and the geochemical characteristics of the site.

7.2.1.8 Human interference

The potential for human interference after the closure of the repository requires an analysis of (1) the natural resources at or near a site, addressing historical, current, and future exploration for, and uses of, these resources, and (2) site ownership and control. Evaluations of these two separate technical guidelines are provided below.

7.2.1.8.1 Natural resources

The qualifying condition for natural resources is as follows:

This site shall be located such that--considering permanent markers and records and reasonable projections of value, scarcity, and technology--the natural resources, including ground water suitable for crop irrigation or human consumption without treatment, present at or near the site will not be likely to give rise to interference activities that would lead to radionuclide releases greater than those allowable under the requirements specified in §960.4-1.

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-8), three major considerations are identified that influence the favorability of the sites. In decreasing order of importance, they are (1) evidence of subsurface mining, resource extraction, and drilling sufficient to affect containment and isolation; (2) potential for foreseeable human activities that could affect containment and isolation; and (3) potential for postclosure intrusion for resource extraction. Although the major considerations are listed in decreasing order of importance, the differences in their importance are small, particularly between the second and the third considerations.

Evaluation of the sites in terms of the major considerations

Evidence of subsurface mining, resource extraction, and drilling sufficient to affect containment and isolation. This consideration assesses the potential effects on waste containment and isolation of existing mines and drillholes within the site. Contributing factors include the presence of active and closed mines as well as evidence of deep drilling and related resource extraction. This consideration is derived from the second and the third potentially adverse condition and is the most important major consideration because existing mines or drill holes could act as pathways for radionuclide migration to the accessible environment. A summary of the evaluation for each site follows.

At the Davis Canyon site, existing uranium mines extend to a maximum depth of 11 meters (35 feet) and are restricted to the Chinle Formation, which has been eroded from most of the repository operations area. These existing excavations are not thought to be extensive enough or deep enough to affect the repository. No drilling is known to have occurred within the site. The nearest hydrocarbon-exploration borehole of appreciable depth is 8 kilometers (5 miles) from the boundary of the repository operations area.

There is no subsurface mining at the Deaf Smith site. There are no known wells that penetrate below the Ogallala aquifer and no known hydrocarbon-exploration holes at the site. Deep drilling at the site is unlikely to have occurred in the past.

Table 7-8. Guideline-condition findings by major consideration--natural resources^{a, b}

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: EVIDENCE OF SUBSURFACE MINING, RESOURCE EXTRACTION, AND DRILLING SUFFICIENT TO AFFECT CONTAINMENT AND ISOLATION					
Potentially adverse condition 2					
Evidence of subsurface mining or extraction for resources within the site if it could affect waste containment or isolation.	NP	NP	NP	NP	NP
Potentially adverse condition 3					
Evidence of drilling within the site for any purpose other than repository-site evaluation to a depth sufficient to affect waste containment and isolation.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 2: POTENTIAL FOR FORESEEABLE HUMAN ACTIVITIES SUFFICIENT TO AFFECT CONTAINMENT AND ISOLATION					
Potentially adverse condition 5					
Potential for foreseeable human activities such as ground-water withdrawal, extensive irrigation, sub-surface injection of fluids, underground pumped storage, military activities, or the construction of large-scale surface-water impoundments—that could adversely change portions of the ground-water flow system important to waste isolation.	NP	NP	P	NP	NP
MAJOR CONSIDERATION 3: POTENTIAL FOR POSTCLOSURE INTRUSION TO EXTRACT RESOURCES					
Favorable condition 1					
No known natural resources that have or are projected to have in the foreseeable future a value great enough to be considered a commercially extractable resource.	NP	NP	NP	NP	P
Favorable condition 2					
Ground water with 10,000 parts per million or more of total dissolved solids along any path of likely radio-nuclide travel from the host rock to the accessible environment.	P	P	NP	P	NP

Table 7-8. Guideline-condition findings by major consideration--natural resources^{a,b} (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 3: POTENTIAL FOR POSTCLOSURE INTRUSION TO EXTRACT RESOURCES (Continued)					
Potentially adverse condition 1					
Indications that the site contains naturally occurring materials, whether or not actually identified in such form that (i) economic extraction is potentially feasible during the foreseeable future or (ii) such materials have a greater gross value, net value, or commercial potential than the average for other areas of similar size that are representative of, and located in, the geologic setting.	P	P	P	P	NP
Potentially adverse condition 4					
Evidence of a significant concentration of any naturally occurring material that is not widely available from other sources.	NP	NP	NP	NP	NP

^a Key: NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the condition is present at the site.

^b Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

Current and past mining or extraction activities in the area of the Hanford site include some quarrying for sand and gravel as well as a small natural gas field that ended production in 1941. The quarries are excavated pits that are generally less than 18 meters (60 feet) deep. The gas field was located approximately 11 kilometers south of the site. No other current or past production of hydrocarbons has been reported within 100 kilometers of the larger Hanford Site. Recent hydrocarbon exploration in the Columbia Plateau has been focused on the sedimentary sequence beneath the basalt; wells drilled to date have been noncommercial, but some natural gas has been recovered. Although methane has been found as dissolved gas in ground water from the Grande Ronde Formation beneath the site, the hydrocarbon potential for this area is speculative at best. Boreholes drilled near the site for purposes other than repository-site evaluation are significantly shallower than the candidate repository horizon and would not affect waste containment or isolation.

At the Richton site, there is no evidence of boreholes, shafts, or other excavations that penetrate the repository horizon within the salt dome. Eight mineral-exploration boreholes have been drilled into salt with a maximum reported penetration of 6.4 meters (21 feet). Within 10 kilometers (6.2 miles) of the dome, 34 sulfur-exploration wells and 32 petroleum-exploration wells have been drilled. The water wells within the area are shallow (less than 366 meters (1,200 feet)) and are drilled into the upper aquifer. The closest fluid-injection wells are at least 4.8 kilometers (3 miles) from the flank of the dome. Waste containment and isolation are not expected to be significantly affected by the presence of shallow boreholes or the potential for increased dissolution associated with the petroleum-exploration wells on the sloping flank of the dome.

There has been no subsurface mining or extraction of resources at Yucca Mountain. There is little likelihood that unknown excavations exist at the site other than shallow prospecting pits. Before the repository investigations began, one borehole had been drilled 7 kilometers (4 miles) southeast of the site (water well J-13), and another had been drilled approximately 15 kilometers (9 miles) to the northeast (water well J-12). There has been no drilling at Yucca Mountain for purposes other than repository-site evaluation.

Potential for foreseeable human activities that could affect containment and isolation. Factors contributing to this consideration include the potential for ground-water withdrawal, irrigation, the injection of fluids, underground pumped storage, and large-scale surface-water impoundments. Changes to the site's ground-water system can directly affect the releases of radionuclides to the accessible environment. This consideration is derived from the fifth potentially adverse condition and is the second most important major consideration. Changes to the site's ground-water system can directly affect the releases of radionuclides to the accessible environment. This consideration is not as important as the first major consideration because it is based on projected, more speculative human activities that may affect isolation, whereas the first consideration is based on existing evidence of resources that could affect isolation.

In assessing the likelihood of postclosure intrusion, the DOE will consider the estimated effectiveness of the permanent markers and records required by NRC regulations in 10 CFR Part 60. Human-intrusion events are considered to be credible only if it is assumed that the monuments provided for in the NRC regulations are permanent enough to serve their intended purpose. Thus, in evaluating this major consideration, the environmental assessments have qualitatively considered the effectiveness of markers and records in reducing the likelihood of human intrusion in the controlled area. A summary of the evaluation for each site follows.

Because of limited potable water and resources within and near the Davis Canyon site, the potential for foreseeable human activities to adversely affect the ground-water-flow system is expected to be very low.

At the Deaf Smith site, good-quality ground water that is suitable for irrigation and domestic use is drawn entirely from the Ogallala aquifer. The ongoing depletion of the Ogallala aquifer will not reverse the downward flow potential at the site. The potential for the subsurface injection of fluids is considered to be low because of the low potential for petroleum development in the future.

At the Hanford site, there is a potential for ground-water withdrawal for irrigation. Insufficient data are available to determine whether such human activities could adversely change portions of the ground-water flow system that are important to waste isolation. However, it is believed that, even if portions of the ground-water-flow system were to change, there would be no significant effect on waste isolation itself.

At the Richton site, the potential to adversely affect the ground-water-flow system is expected to be very low. Potential human activities are very unlikely to affect ground-water travel through the salt stock; this includes activities that may change fresh-water aquifers. The likelihood of pumped storage in the controlled area is also expected to be very low, considering the permanent markers and records.

Although potable ground water is present at the Yucca Mountain site, future generations are not likely to drill for water from the top of Yucca Mountain, because it would be easier to drill for water in the surrounding areas. Because isolation depends primarily on the thick unsaturated zone, withdrawal of water outside the controlled area would not adversely affect the ground-water system important to isolation.

Potential for postclosure intrusion to extract resources. This consideration includes estimates of, and the potential for, postclosure intrusion for resource extraction. Contributing factors include the presence or indication of resources (including water) at the site, their value, scarcity, and depth, as well as their availability from other sources. This condition is derived from the first and the second favorable conditions and the first and the fourth potentially adverse conditions. This consideration is third in importance because the potential for resources is based on speculative or indirect evidence. Nevertheless, this consideration is significant because exploration for, or the extraction of, resources can create pathways for radionuclides to reach the accessible environment. A summary of the evaluation for each site follows.

Uranium and vanadium deposits are present in the vicinity of the Davis Canyon site, and some production has occurred at the site itself; however, the uranium resources at the site are believed to be less significant than those in other parts of southeastern Utah. In addition, commercial-grade underground potash deposits are present in the vicinity of the site, but they may not be economic because they are located at excessive depths and are less extensive than deposits in other parts of Utah. Small amounts of sand, gravel, and potable water have been extracted in the vicinity of the site. None of these resources has greater potential within the area of the site than outside it. Potential hydrocarbon resources are believed to be significantly smaller within the site than in similar areas outside the site. The ground-water is of poor quality, with the total dissolved solids exceeding 10,000 parts per million.

At the Deaf Smith site, ground water is being extracted from the Ogallala aquifer. The use of this water resource does not pose a threat to the long-term integrity of the repository. Ground water along the likely pathways of radionuclide travel is not suitable for human consumption because it contains dissolved solids at concentration exceeding 10,000 parts per million. The hydrocarbon potential at the site is not considered to be significant, but exploration for oil and gas in the future cannot be discounted. No other mineral resources, such as uranium and construction aggregates, are present in unique quantities at the site. The bedded salt may be considered a halite resource. There are no known concentrations of naturally occurring materials that are not widely available from other sources.

At the Hanford site, there are no known metallic or petroliferous resources that have or are projected to have a value great enough to be commercially extractable. However, there are indications that the site contains ground-water resources and natural gas that may be economically feasible to extract in the foreseeable future. Although hydrocarbon source beds may exist beneath the basalt, there is no evidence to date of significant concentrations of any naturally occurring resources that are unique to the site.

The Richton Dome is the largest of 35 shallow salt domes in the Mississippi salt basin. Because of its size and depth, it is an excellent candidate for underground storage. The purity of the salt (91 percent sodium chloride) also indicates that the dome may be a candidate for salt extraction by solution mining or conventional mining methods. In comparison with other shallow salt domes, the potential for storage or salt extraction at the Richton Dome is above average because of its large size, even though salt is widely available from other sources and the dome's potential use as an underground storage facility is not unique. Commercial hydrocarbon resources are not known to exist at the Richton Dome.

Yucca Mountain has no energy or mineral resources for which extraction is feasible in the foreseeable future. No known resources are present at Yucca Mountain that have greater commercial potential than those in other areas in its geologic setting, nor is there evidence of any significant concentration of potentially valuable resources at Yucca Mountain. The mineral-resource potential of the Yucca Mountain site is considered low. The ground water along likely flow paths of radionuclide travel has less than 10,000 parts per million of total dissolved solids.

Summary of comparative evaluation

On the basis of the three major considerations, Yucca Mountain is the most favorable site; Davis Canyon, Deaf Smith, and Hanford are comparable; and Richton is the least favored site. The differences among the sites, however, are small. This judgment is based on the fact that there is no evidence at any of the sites of subsurface mining, extraction, or drilling sufficient to affect containment or isolation. There is also no evidence at any of the sites of a significant or unique concentration of any naturally occurring mineral or energy resources. It is expected that the use of permanent markers and records will reduce to very low values the likelihood of human intrusion within the controlled area at each of the sites.

The likelihood of any resource occurring at the Yucca Mountain site appears to be very low. The potential use of the deep aquifer outside the controlled area will not affect containment and isolation.

The Davis Canyon, the Deaf Smith, and the Hanford sites are approximately equal in favorability on the basis of the speculative potential for resources. There is a very small potential for the use of the shallow aquifer outside the controlled area at the Hanford site to affect the ground-water-flow system important to isolation.

Richton Dome is the least favorable site because of the speculative potential for resources, the possibility of undetected boreholes, and the potential for using the dome for underground pumped storage.

7.2.1.8.2 Site ownership and control

The purpose of the postclosure guideline on site ownership and control is to help ensure that the repository can function far into the future without adverse human interference. This guideline specifies that the DOE, in accordance with the requirements of the 10 CFR Part 60, is to obtain ownership of, and surface and subsurface rights to, land and minerals within the controlled area of the repository. A similar guideline on site ownership is provided for the preclosure period. The purpose of the preclosure guideline is to ensure that surface and subsurface activities during repository operation will not be likely to lead to radionuclide releases greater than those allowed by applicable regulations.

The DOE has determined that the necessary land area and controls are the same for both the postclosure and the preclosure periods at the five nominated sites. Whichever site is selected, the DOE must obtain ownership as well as surface and subsurface rights before commencing preclosure activities; there is no basis for distinguishing among the sites on their site ownership and control status at the beginning of the postclosure period. Therefore, all sites are considered to be equally favorable for this guideline.

7.2.2 POSTCLOSURE SYSTEM GUIDELINE

The results of preliminary system-performance assessments are described in Section 6.4.2 of each environmental assessment and briefly reviewed here. These preliminary assessments are based on limited geologic, hydrologic, and geochemical information, preliminary conceptual models, and relatively simple analytical techniques. The DOE is therefore not yet prepared to provide assurance that regulatory criteria will be met at any of the sites. These preliminary assessments do, however, appear adequate for evaluating the sites against the postclosure system guideline. However, the different approaches to the evaluation of performance, the preliminary nature of these assessments, and the uncertainties in the parameters on which the analyses are based all limit the ability to compare the sites in the manner required by the implementation guidelines for site comparisons that will support the recommendation of a site for development as a repository. To provide a comparative context for understanding the postclosure system guideline evaluation in Chapter 6, a brief discussion of the evaluation of each of the sites with respect to each of the capabilities addressed by the guideline is presented below.

The guideline addresses the following capabilities of the geologic setting at a site:

1. The capability of the geologic setting at the site to allow for the physical separation of the waste from the accessible environment after closure in accordance with the requirements of the EPA standard in 40 CFR Part 191, Subpart B, as implemented by 10 CFR Part 60.
2. The capability of the geologic setting at the site to allow for the use of engineered barriers to ensure compliance with the requirements of the EPA and the NRC. Two requirements are pertinent here: (1) the time of substantially complete containment (i.e., a period between 300 and 1,000 years); and (2) the limit on the rate of radionuclide releases from the engineered-barrier system (i.e., one part in 100,000 per year of the individual radionuclide inventory or one part in 100,000 per year of the total inventory calculated to be present at 1,000 years after repository closure, whichever is greater).

Capability for waste isolation. The results of the preliminary assessments indicate that the EPA standards would be met at all of the sites. For example, the mean time of ground-water travel from the repository to the accessible environment is expected to be much longer than 10,000 years at each site. On this basis alone, there is little likelihood of any release for 10,000 years or, more specifically, of exceeding the EPA standard for cumulative releases during this period. In fact, the results of the calculations for the preliminary assessments indicate that releases are likely to be negligible for much more than 10,000 years at each site. Similarly, calculations of ground-water quality indicate that the EPA's ground-water protection and individual-protection requirements will be met at each of the sites. For the Hanford site, the calculations show to a high level of confidence that less than 50 curies of iodine-129 and carbon-14--and no other radionuclides--would be released to the accessible environment in 100,000 years. The calculations for Yucca Mountain indicate that less than 100 curies

of technetium-99 and negligible quantities of any other radionuclide could be released in 100,000 years. The analyses for the salt sites show no release in 100,000 years under expected repository conditions.

Because of the different characteristics of each of the sites, different approaches to the performance analyses and varying levels of conservatism have been used for each site. For example, the constraint on release due to the slow degradation of the waste form was not taken into account in the analysis of the Hanford site. The analysis of the Yucca Mountain site does not consider the spatial distribution of waste packages throughout the repository, but assumes that the release occurs from a single location in the host rock. Transport and retardation in the saturated zone are not considered in these analyses as well. The margin of conservatism resulting from such assumptions in each case is not known at present. However, it is believed to be sufficient to compensate for the uncertainties in the site data. The preliminary performance assessments do not provide evidence to support a finding that any of the sites would not adequately isolate the waste from the accessible environment.

Requirements for engineered-barrier performance. Preliminary assessments of the engineered-barrier system indicate that this system would meet the regulatory performance objectives at all sites. For example, the analyses of waste-package performance indicate that the container lifetime is expected to exceed the 300- to 1,000-year requirement for substantially complete containment at each site. The expected container lifetime for the Hanford site exceeds 6,000 years. The analysis of the container under the conditions of the Yucca Mountain site gives a lower-bound estimate of 3,000 years and an expected lifetime of 30,000 years. At the salt sites, the lifetime of the container is calculated to be even longer, because it is expected that sufficient water will not be available to cause corrosion failure of the waste package.

For each site, the calculations of the rate of radionuclide release after the failure of the waste package suggest that the criterion for the rate of release from the engineered-barrier system would not be exceeded. At the Hanford site, the release rate for most radionuclides would be well below the regulatory criterion because of the diffusion-limited transport and the limited solubility of these radionuclides in the ground water at the site. For the few radionuclides that are highly soluble, the calculated release rates are less than 4 percent of the release-rate limit.

Without taking into account the solubility of the radionuclides themselves, the fractional release rate calculated for the Yucca Mountain site is 2.5×10^{-9} per year, well below the limit of 1×10^{-5} per year, because of the low rate expected for waste-form dissolution. At the salt sites, since it is expected that the waste packages will last indefinitely, the rate of radionuclide release from the engineered-barrier system is expected to be zero.

Extremely conservative assumptions were used in making these estimates. For example, in all cases the calculations are for releases from the waste package, which is expected to provide an upper bound to the release from the total engineered-barrier system. In addition, any containment offered by the

spent-fuel cladding was not taken into account in any of the analyses. In the analysis of the salt sites and of the Hanford site, the slow dissolution of the waste form, which can limit the rate of radionuclide release, was not taken into account. In the analyses of the salt sites and of the Yucca Mountain site, it was assumed that all packages fail simultaneously. Again, the degree of conservatism provided by these assumptions is not known at present. However, the analyses appear to be sufficient to indicate that there is no evidence that the performance criteria for the waste package and other engineered barriers would not be met at each of the nominated sites. Furthermore, the available data and the preliminary analyses based on these data have not identified any conditions or features at any of the sites that would prevent these engineered components from meeting the performance requirements.

The different approaches to the evaluation of performance, the preliminary nature of these assessments, and the uncertainties in the parameters on which the analyses are based all limit the ability to compare the sites in terms of these results. In each case the analyses are very simple. The interactions of the various factors that determine subsystem and system performance are not yet known. Finally, the analyses that can be conducted at present are too simple to address the full range of uncertainties that should be addressed in order to provide an adequate comparison of the sites. Therefore, because of the preliminary nature of these performance assessments, it does not appear that a comparison between and among the sites on the basis of the preclosure system guideline is practicable at present.

7.3 COMPARISON OF SITES ON THE BASIS OF PRECLOSURE GUIDELINES

The preclosure guidelines address (1) preclosure radiological safety; (2) the environmental, socioeconomic, and transportation-related impacts associated with repository siting, construction, operation, and closure; and (3) the ease and cost of repository siting, construction, operation, and closure. Both technical and system guidelines are provided for each of these three categories.

7.3.1 PRECLOSURE RADIOLOGICAL SAFETY

7.3.1.1 Technical guidelines

There are four technical guidelines on preclosure radiological safety: (1) population density and distribution, (2) site ownership and control, (3) meteorology, and (4) offsite installations and operations. The objective of these guidelines is to protect the health and safety of the public and the workers at the repository by keeping exposures to radiation within the limits prescribed by regulations. This section presents a comparative evaluation of the five nominated sites against these guidelines.

7.3.1.1.1 Population density and distribution

The qualifying condition for population density and distribution is as follows:

The site shall be located such that, during repository operation and closure, (1) the expected average radiation dose to members of the public within any highly populated area will not be likely to exceed a small fraction of the limits allowable under the requirements specified in §960.5-1(a)(1), and (2) the expected radiation dose to any member of the public in an unrestricted area will not be likely to exceed the limit allowable under the requirements specified in §960.5-1(a)(1).

Major considerations

On the basis of the qualifying, favorable, potentially adverse and disqualifying conditions for this guideline (Table 7-9), two major considerations are identified that influence the favorability of the sites with respect to population density and distribution. These major considerations are (1) remoteness of the site from highly populated areas and (2) the population density at the site, near the site, and in the general region of the site. These major considerations are of equal importance and are in turn influenced by several more-specific contributing factors, which are discussed below.

Evaluation of the sites in terms of the major considerations

Remoteness. The remoteness of a site is measured by its distance from highly populated areas of 2,500 people or more, or from an area with 1,000 or more persons within 1 square mile. This major consideration is derived from the second favorable condition and the second potentially adverse condition (see Table 7-9). It relates to the qualifying condition in that the potential for radiation exposure increases with proximity to population concentrations. The second favorable condition refers to the remoteness of the site from highly populated areas, and the second potentially adverse condition addresses the proximity of the site to populated areas and areas with at least 1,000 individuals in an area that is 1 mile by 1 mile. The two contributing factors related to this major consideration are (1) the air distance of the site from population concentrations and (2) the size of those concentrations. Specifically, the closer a site is to highly populated areas, and the larger such population concentrations are, the less favorable is the site. A summary of the evaluation for each site follows.

The immediate vicinity of the Davis Canyon site contains no highly populated areas. Moab, with a population of 5,333, is the closest and is approximately 33 miles from the boundary of the controlled area. Moab is also the nearest 1-square mile area with a population of at least 1,000 persons.

The Deaf Smith County site is approximately 17 miles north of Hereford, with a population of 15,853. Hereford is also the nearest area with at least 1,000 persons in a 1-square-mile area.

Table 7-9. Guideline-condition findings by major consideration-
population density and distribution^{a, b}

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: REMOTENESS FROM HIGHLY POPULATED AREA					
Favorable condition 2					
Remoteness of the site from highly populated areas.	P	P	P	P	P
Potentially adverse condition 2					
Proximity of the site to highly populated areas, or to areas having at least 1,000 individuals in an area 1 mile by 1 mile as defined by the most recent decennial count of the U.S. census.	NP	NP	NP	P	NP
MAJOR CONSIDERATION 2: POPULATION DENSITY					
Favorable condition 1					
A low population density in the general region of the site.	P	P	P	P	P
Potentially adverse condition 1					
High residential, seasonal, or daytime population density within the projected site boundaries.	NP	NP	NP	NP	NP

^a Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

^b Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

At the Hanford site, Sunnyside is the nearest highly populated area. It has a population of 9,229 and is approximately 15 miles southwest of the site. Sunnyside is also the closest 1-square-mile area with a population of at least 1,000.

At the Richton site, the town of Richton, with a population of 1,205 within a 1 square mile, is adjacent to the proposed boundary of the controlled area. However, the town is 2 miles from the proposed boundary of the surface facilities of the repository. The nearest highly populated area is Petal/Hattiesburg with a population of 49,300; it is 25 kilometers from the boundary of the site.

The Yucca Mountain site is remote from highly populated areas or 1-square-mile areas with a population of at least 1,000. Las Vegas Valley, the nearest highly populated area, is at a distance of approximately 85 miles.

Population density. Population density is evaluated for each site on the basis of density within the projected site boundaries, near the site, and in the general region of the site. For this analysis, "near the site" is defined as being within 10 miles of the site and "in the general region" as being within 50 miles. This major consideration is derived from the first favorable condition and the first potentially adverse condition (see Table 7-9). It relates to the qualifying condition in that a larger number of people are potentially exposed to radioactive releases as the population density in the region of a site increases. The first favorable condition is a low population density in the general region of the site, and the first potentially adverse condition addresses high residential, seasonal, or daytime population density within the projected site boundaries.

In the evaluation of this major consideration, a "low population density" is defined as being less than the average population density of the contiguous United States in 1980, or 76 persons per square mile. This major consideration is also closely related to the third disqualifying condition for this guideline, which is related to emergency planning. Specifically, as population density near the site increases, a more extensive emergency-preparedness plan is required, since protective measures would have to be taken on behalf of a larger number of people in the event of an accident. As the density on the site, near the site, and within the general region of the site increases, the favorability of the site decreases. A summary of the site evaluation for this consideration follows. The site-specific information used in the evaluation is summarized from Section 6.2.1.2 of the environmental assessments for the five nominated sites.

There is no residential or seasonal population within the projected boundaries of the Davis Canyon site. The daytime population is limited to an estimated peak of seven offroad-vehicle users. The onsite population density is therefore far below the national average. About 282 people are estimated to live within 10 miles of the site. The population density in the general region is also far below the national average, at 3.8 persons per square mile.

The Deaf Smith County site is estimated to have 27 residents within its boundaries. The seasonal population density at the site is about seven persons per square mile assuming that the 10,440 migrant workers who were in

Deaf Smith County in 1975 are evenly distributed throughout the county. The combined residential, seasonal, and daytime population density within the site boundary is approximately 10 persons per square mile. The population within 10 miles of the site is estimated to be 1,739. The population density in the general region of the site is 24 persons per square mile.

Although there are no residences or seasonal population at the Hanford site, approximately 700 persons work within the site boundary at any given time, which is equivalent to a population density of 39 persons per square mile. In addition, 4,800 persons are employed in nuclear energy jobs in the vicinity of the site. (However, because these workers receive training in safety and evacuation procedures, they are better prepared than the general public to respond to radiological hazards.) There are approximately 110 people within 10 miles of the site. The population density in the general region of the site is 43 persons per square mile. Federal ownership of the Hanford site reduces the uncertainty associated with future population growth in the area.

The residential population within the proposed controlled area of the Richton site is about 140 people, assuming that there are 50 households with an average size of 2.8 persons. However, there are no residences within the proposed restricted area. Seasonal population fluctuations are expected to be minimal. The daytime population may vary by 100 because a school is located in the southeast portion of the area of the Richton Dome. The population within 10 miles is approximately 4,610. The population density in the general region is 40 persons per square mile.

There are no residences within 6.2 miles of the Yucca Mountain site and no seasonal or daytime populations within the site boundaries. About 5,200 workers are employed at the Nevada Test Site, but most of their activities are conducted on the opposite side of the Nevada Test Site. Because of their experience with nuclear research and testing, workers at the Nevada Test Site are better prepared than members of the general public to deal with radiological hazards. The population density in the general region of the site is approximately 2.5 people per square mile. Federal ownership of the site and the surrounding area reduces the uncertainty of population growth near the site.

Summary of the comparative evaluation

Yucca Mountain is the most favorable site for both major considerations. There are no highly populated areas within 50 miles of the site, and the regional population density is the lowest of all the sites. In addition, there is no residential or seasonal population on or near the site. Davis Canyon is less favorable because it is 33 miles from the highly populated area of Moab, which has a population of 5,333. Nonetheless, the site is remote in comparison with the remaining sites. The population density in the region is also very low--288 people are located within 10 miles of the site. The Hanford site is 15 miles from Sunnyside, which has a population of 9,229. The population density in the region is 43 persons per square mile. These two factors reduce the favorability of the site. There are only 110 residents within 10 miles of the Hanford site, and the 4,800 nuclear energy workers in the vicinity of the site are better prepared than other members of the general

public to deal with radiological hazards. The Deaf Smith site is 17 miles from Hereford, which has a population of 15,853. The population density in the region is 24 persons per square mile, and 1,739 people live within 10 miles of the site. The Richton site is proximate to the town of Richton, and 4,610 people live within 10 miles. The population density in the region is 40 persons per square mile. Since there are 140 people and a school within the controlled area, and the highly populated area of Petal and Hattiesburg with a population of 49,300 is 16 miles away, the Richton Dome is the least favorable site for this guideline.

7.3.1.1.2 Site ownership and control

The qualifying condition for site ownership and control is as follows:

The site shall be located on land for which the DOE can obtain, in accordance with the requirements of 10 CFR 60.121, ownership, surface and subsurface rights, and control of access that are required in order that surface and subsurface activities during repository operation and closure will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in §960.5-1(a)(1).

Major consideration

On the basis of the qualifying, favorable, and potentially adverse conditions of this guideline (Table 7-10), one major consideration is identified that influences the favorability with respect to the qualifying condition. It refers to the kinds of procedures that are available for acquiring land. The major consideration is, in turn, influenced by two contributing factors.

Evaluation of the sites in terms of to the major consideration

The single major consideration for this guideline is the complexity of procedures for acquiring the needed land. This consideration is derived from the favorable condition and the potentially adverse condition (see Table 7-10). The favorable condition addresses whether the DOE has present ownership and control of the site. The potentially adverse condition identifies three means of acquiring land: voluntary purchase-sell, condemnation, and undisputed agency-to-agency transfer. If the DOE is unable to acquire land through one of these means, Congressional action will be required. Each of these land-acquisition mechanisms involves different legal procedures.

There are two ways the DOE can acquire private or State land: voluntary purchase-sell and condemnation. Voluntary purchase-sell means that a landowner voluntarily sells his land to the DOE under the provisions of the Uniform Relocation Assistance and Real Property Acquisition Act of 1970. If a landowner is not willing to sell needed property, the DOE can acquire it by right of eminent domain, or condemnation, under the provisions of the Declaration of Taking Act (40 USC Section 258a). The DOE estimates that about 90 days would be required to condemn privately owned land.

Table 7-10. Guideline-condition findings by major consideration--
site ownership and control (preclosure)^{a, b}

Condition ^c	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
Favorable condition					
Present ownership and control of land and all surface and subsurface mineral and water rights by the DOE.	NP	NP	P	NP	NP
Potentially adverse condition					
Projected land-ownership conflicts that cannot be successfully resolved through voluntary purchase-sell agreements, nondisputed agency-to-agency transfers of title, or Federal condemnation proceedings.	P	NP	NP	NP	P

^a Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

^b Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

^c Both conditions in this table are related to one major consideration: complexity of procedures for acquiring needed land.

There are two ways that the DOE can obtain jurisdiction over lands that are currently controlled by another Federal agency: agency-to-agency transfers and legislative transfer by Congress. The DOE can acquire land from another Federal agency for up to 20 years under the provisions of the Federal Land Policy and Management Act of 1976. However, to meet the requirements of applicable NRC regulations (10 CFR 60.121), the DOE must obtain permanent jurisdiction over the repository operations area and the controlled area. This permanent withdrawal will require a legislative transfer.

In evaluating the sites against this guideline, the DOE considered what property would be required for repository construction, operation, closure, and decommissioning. Land-acquisition procedures, such as leasing, that might be employed during site characterization were not considered.

Sites for which land will be easier to acquire from a procedural and legal point of view are more favorable. This does not mean that the DOE discounts the socioeconomic impact of acquiring lands, especially privately owned land. The socioeconomic impacts of land acquisition are considered under the socioeconomic guideline. The DOE recognizes, for example, that the condemnation of privately owned lands will disrupt the lives of displaced landowners. Nevertheless, condemnation is legally more straightforward than obtaining the Congressional authorization that would be needed to acquire certain lands under the control of other Federal agencies. The DOE estimates that about 90 days would be required for condemnation, whereas a Federal-land transfer requiring Congressional authorization could take longer and the result could be less certain. Thus, from a strictly procedural point of view, it is easier for the DOE to acquire permanent jurisdiction over State and private lands than Federal lands.

The complexity of procedures for acquiring land depends, in turn, on current ownership (DOE, other Federal agency, State, or private) and the number of landowners. Current ownership determines which acquisition procedures are available. Similarly, the greater the division among landowners (Federal, State, private), the more complicated the overall land-acquisition procedures. A summary of the evaluation for each site follows.

Most of the Davis Canyon site is Federal land controlled by the Bureau of Land Management (BLM), although small portions are owned by the State of Utah and private parties. A Congressional action would be required to obtain permanent jurisdiction over the BLM portion of the site. Although the DOE would prefer to acquire State and private lands by voluntary purchase-sell agreements, the land could be acquired by condemnation if necessary.

The Deaf Smith site is privately owned, and ownership is divided among at least eight parties. The Richton site is also on private lands with ownership divided among many parties. Although the DOE would prefer voluntary purchase-sell agreements with the current owners, the land can be acquired by condemnation.

The DOE controls all surface and subsurface rights to the Hanford site and the surrounding area. The DOE would not have to acquire any land for a repository at Hanford.

The Federal land of the Yucca Mountain site is under the control of three agencies: the DOE, the BLM, and the Department of Defense (the Air Force). Congressional action would be required to permit a permanent transfer of land from the BLM and the Air Force to the DOE, but the action is not expected to be disputed by these agencies.

Summary of the comparative evaluation

The Hanford site is the most favorable for the preclosure guideline on site ownership and control because the DOE has control over the entire site. The Deaf Smith and the Richton sites are on private land that can be acquired by voluntary purchase-sell agreements or the right of eminent domain. Control over the Yucca Mountain site is divided among three Federal agencies, and Congressional action would be required to permit a permanent transfer to the DOE. The Davis Canyon site is the least favorable because the ownership of land is divided among the BLM, the State of Utah, and private parties, and a combination of actions (voluntary purchase-sell agreements, condemnation, and Congressional action) would be required to acquire the needed land.

7.3.1.1.3 Meteorology

The qualifying condition for meteorology is as follows:

The site shall be located such that expected meteorological conditions during repository operation and closure will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in §960.5-1(a)(1).

Major considerations

The qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-11) led to the identification of two major considerations that influence favorability with respect to the qualifying condition. These major considerations, in order of decreasing importance, are (1) conditions that affect the transport of radionuclide releases in the atmosphere and the significance of transport, and (2) extreme weather phenomena. The transport consideration addresses prevailing meteorological conditions, while the extreme weather consideration addresses specific episodes. These major considerations are influenced by several contributing factors which are discussed below.

Evaluation of the sites in terms of the major considerations

Conditions that affect transport and the significance of transport. This major consideration addresses meteorological conditions that affect the transport of airborne radionuclide releases to unrestricted areas where the general public might be exposed. Contributing factors are the dispersion characteristics of the atmosphere, wind speed and direction, episodes of stagnation, atmospheric mixing levels, the terrain, and the locations of nearby populations. This is the most important major consideration under this guideline because the potential for a preferential transport of radionuclides

Table 7-11. Guideline-condition findings by major consideration—
meteorology^{a, b}

Condition ^c	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
Favorable condition					
Prevailing meteorological conditions such that any radioactive releases to the atmosphere during repository operation and closure would be effectively dispersed, thereby reducing significantly the likelihood of unacceptable exposures to any member of the public in the vicinity of the repository.	NP	P	P	P	P
Potentially adverse condition 1					
Prevailing meteorological conditions such that radioactive emissions from repository operation and closure could be preferentially transported toward localities in the vicinity of the repository with higher population densities than are the average for the region.	P	P	P	P	NP
Potentially adverse condition 2					
History of extreme weather phenomena—such as hurricanes, tornadoes, severe floods, or severe and frequent winter storms that could significantly affect repository operation or closure.	P	P	NP	P	NP

^a Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

^b Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

^c All of the conditions in this table are related to one major consideration: conditions that affect transport and the significance of transport.

directly affects a site's ability to meet the requirements of the preclosure system guideline on radiological safety. In terms of the significance of transport, the doses delivered to the maximally exposed person beyond the boundaries of the site are estimated to be well within the limits of 40 CFR 191 for each site. The estimate is based partly on estimates of radionuclide releases to unrestricted areas; at each site, these releases would be within the limits specified by the NRC in 10 CFR Part 20. A summary of the evaluation for each site follows.

For the Davis Canyon site, representative offsite data indicate that relatively high mixing heights and moderate average wind speeds prevail. Dispersion may be hampered by the rugged surrounding terrain, and local inversions (about 39 episode-days per year) can cause air to be trapped in valleys. The prevailing wind directions at the site are from the southwest. The only population concentration in the downwind direction within 50 miles of the site is La Sal Junction, which is 19 miles away.

For the Deaf Smith site, representative offsite data indicate that neutral atmospheric stability conditions and high average wind speeds predominate, resulting in relatively good dispersion conditions. The prevailing mixing level, the infrequent occurrences of stagnation episodes, and the generally flat terrain at the site also favor dispersion. The prevailing wind directions at the site are from the southwest. The nearest population concentrations in the downwind direction are Masterson and Exell, which are both about 50 miles away.

The data recorded at the Hanford Meteorological Station indicate that dispersion conditions at the Hanford site are generally good. Favorable conditions include moderate average wind speeds and deep mixing levels. The prevailing wind directions are from the northwest. The Tri-Cities area (Richland, Kennewick, and Pasco) is 22 to 28 miles from the site in the predominant downwind direction.

Representative offsite data used for the analysis indicate that atmospheric stability and average wind-speed conditions favor fair to good dispersion. Mixing-level heights, the relative infrequency of stagnation episodes, and the flat to rolling terrain also favor good dispersion. The prevailing wind directions at the site are from the south and southeast. The nearest large population concentrations located in the downwind direction are Laurel and Bay Springs, which are 24 and 40 miles, respectively, from the site.

Meteorological data recorded at Yucca Flat indicate that wind velocities, atmospheric stability, and mixing heights at the site should provide effective atmospheric dispersion. Topographic conditions should also favor dispersion. The nearest population concentrations are Beatty, which is 19 miles to the west, and Amargosa Valley, which is 14 to 28 miles south of the site. Beatty and Amargosa Valley are downwind of the site less than 5 percent and about 10 percent of the time, respectively.

Extreme-weather phenomena. This major consideration addresses the historical frequency and intensity of extreme-weather phenomena--such as hurricanes, tornadoes, floods, and winter storms--that could have a significant effect on repository operation or closure. It relates to the

concern in the qualifying condition with meteorological conditions that could lead to unacceptable levels of exposure to persons in unrestricted areas. It is derived from the second potentially adverse condition of the meteorology guideline. This consideration is less important than the first major consideration because, unlike atmospheric transport characteristics, which tend to reflect prevailing meteorological conditions, extreme-weather phenomena are episodic conditions. A summary of the evaluation for each site follows.

Hurricanes are not known to occur in the Davis Canyon site area, and tornadoes are unlikely. The area is not subject to heavy snowfalls, but snowfalls greater than 1 inch occur 10 to 20 days per year. Local flooding or local heavy fog may occur about 8 days per year.

Extreme weather such as local flooding, hurricanes, tornadoes, freezing rain, and heavy fog occur in the area of the Deaf Smith County site about 29-31 days per year. The area also experiences dust storms with winds exceeding 65 mph. There are usually snowstorms less than one day per year.

Extreme-weather conditions occur infrequently at the Hanford site. Tornadoes are rare, and severe winter storms are seldom experienced.

Local flooding, hurricanes, tornadoes, and heavy fog occur in the Richton site area 30 to 70 days a year. Freezing rain, high winds, or snowstorms usually occur less than one day per year.

The frequency of extreme weather at the Yucca Mountain site is among the lowest in the nation. High winds, snowfall, and tornadoes are rare, and the area does not experience severe local flooding. Sandstorms are common, but they would rarely be severe enough to disrupt repository operation.

Summary of comparative evaluation

The Yucca Mountain site is the most favorable under the meteorology guideline. Meteorological data from Yucca Flat suggest that good dispersion conditions are likely to prevail at the site. Prevailing winds would not be likely to preferentially transport radionuclides toward population concentrations. The Yucca Mountain area has a low frequency and magnitude of extreme weather. Meteorological data from the Hanford Site show good dispersion conditions and a low incidence of extreme weather. The favorability of the Hanford site is reduced by the presence of major population centers in the prevailing downwind direction. The Deaf Smith and the Richton sites are both expected to have good dispersion characteristics. Their favorability is reduced in comparison to the Hanford site because they experience more severe weather. Davis Canyon is the least favorable for meteorology. The favorability of this site is reduced by the presence of a population center in the prevailing downwind direction, reduced dispersion conditions, and a greater frequency of severe weather.

7.3.1.1.4 Offsite installations and operations

The qualifying condition for the preclosure guideline on offsite installations and operations is as follows:

The site shall be located such that present projected effects from nearby industrial, transportation, and military installations and operations, including atomic energy defense activities, (1) will not significantly affect repository siting, construction, operation, closure, or decommissioning or can be accommodated by engineering measures and, (2) when considered together with emissions from repository operation and closure, will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in §960.5-1(a)(1).

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-12), two major considerations influence a site's favorability with respect to the qualifying condition. These major considerations, in order of decreasing importance, are (1) the presence of nearby nuclear installations or operations and (2) the presence of nearby hazardous installations or operations.

Evaluation of sites in terms of the major considerations

Nearby nuclear installations or operations. This major consideration addresses radionuclide releases from atomic-energy defense activities and nuclear installations regulated by the NRC, which could, together with operational releases from the repository, subject the general public to radionuclide exposures above allowable limits. The evaluation accounts for the proximity of nuclear installations and operations to the site and the levels of radionuclide releases that could be expected during accidents and routine operating conditions at these installations. This consideration is derived from the favorable condition and the second potentially adverse condition. It relates directly to the qualifying condition's concern with the potential contribution of other nuclear facilities to radionuclide releases from the repository. This major consideration is assigned greater importance than nearby hazardous installations in this evaluation because of the primary focus in the qualifying condition on compliance with regulations on releases.

In evaluating this consideration, the term "nearby" for offsite installations and operations is defined as the area within 5 miles of the site. The assessment of potential cumulative impacts considers nuclear facilities within 50 miles. A summary of this consideration for each site follows.

At the Davis Canyon site, the only nearby nuclear operations are three uranium mills, which are 36 to 58 miles from the site. The combined radionuclide releases from the uranium mills and a repository at the site would be significantly lower than the specified limits.

Table 7-12: Guideline-condition findings by major consideration—
offsite installations and operations^{a,b}

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: NEARBY NUCLEAR INSTALLATIONS OR OPERATIONS					
Favorable condition 1					
Absence of contributing radioactive releases from other nuclear installations and operations that must be considered under the requirements of 40 CFR 191, Subpart A.	NP	NP	NP	P	P
Potentially adverse condition 2					
Presence of other nuclear installations and operations, subject to the requirements of 40 CFR Part 190 or 40 CFR 191, Subpart A, with actual or projected releases near the maximum value permissible under those standards.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 2: NEARBY HAZARDOUS INSTALLATIONS OR OPERATIONS					
Potentially adverse condition 1					
The presence of nearby potentially hazardous installations or operations that could adversely affect repository operation or closure.	NP	P	P	P	P

^a Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

^b Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

The Deaf Smith site is 48 miles from the Pantex Plant, a major atomic energy defense facility near Amarillo. Releases from this plant are predicted to be only a small fraction of the specified limits and would not significantly contribute to radionuclide levels in the vicinity of the repository. There are no other nuclear facilities in the vicinity.

Commercial nuclear facilities near the Hanford site include one operating nuclear power plant of the Washington Public Power Supply System, commercial site for the disposal of low-level radioactive waste, and a plant that fabricates nuclear fuel. The predicted releases from these facilities are substantially less than the maximum permissible value and would not contribute significantly to radionuclide levels in the vicinity of the repository. DOE-owned nuclear facilities near the repository site include a plutonium-production reactor, the Purex reprocessing plant, and a reactor for testing breeder reactor fuels and components. The postulated worst-case accident at these facilities would result in a radiation exposure at the boundary of the Hanford Site that would be below applicable limits.

The Richton site has no nearby nuclear facilities, nor are there any facilities subject to 40 CFR Part 190 or 40 CFR Part 191, Subpart A, within 50 miles of the site.

At the Yucca Mountain site, there are no nearby nuclear facilities that are subject to 40 CFR Part 190 or 40 CFR Part 191, Subpart A. Potential sources of radionuclide emissions in the area are a commercial site for low-level-waste disposal about 19 miles west of Yucca Mountain, and the research with spent fuel at the Nevada Research and Development Area, which is adjacent to the east side of Yucca Mountain. The releases resulting from the postulated worst-case accident at these facilities would culminate in total radiation releases at the Nevada Test Site boundary below applicable limits. Most of the radioactive emissions from underground nuclear testing at the Nevada Test Site are contained.

Nearby hazardous installations or operations. This major consideration addresses the possible adverse effects of nearby hazardous operations and installations on repository siting, construction, operation, closure, or decommissioning. Such operations and installations could include chemical plants; fuel production, refining, transportation, and storage facilities; pipelines; major transportation routes used that could carry hazardous materials; air traffic associated with nearby airports; military operations areas; toxic materials handling facilities; and sites for hazardous-waste disposal. These facilities or operations are considered hazardous if they could affect repository operations or worker safety. Potential hazards could include shock waves from explosions, incendiary fragments, and flammable or toxic vapor clouds. This major consideration is derived from the first potentially adverse condition. It relates directly to the concern in the qualifying condition with adverse impacts of nearby hazardous installations and operations on repository operation or closure. A summary of the evaluation for each site follows.

At Davis Canyon, there are no hazardous installations within 5 miles. The site is more than 35 miles from the airports at Blanding and Monticello and more than 18 miles from the San Juan County airport. The nearest State

highway is more than 5 miles from the site. Therefore, there are no hazardous installations or operations that are likely to affect a repository at Davis Canyon.

At the Deaf Smith County a 4-inch natural-gas pipeline passes within 3,000 feet of the restricted area, but it does not constitute a hazard to a repository. U.S. Highway 385 passes within 3 miles of the site. Trucks using this highway may carry hazardous cargoes that could affect the repository in a serious transportation accident.

Potentially hazardous installations and operations in the vicinity of the Hanford site include national defense and waste-management facilities. Potentially hazardous facilities include a plutonium-production reactor, a reprocessing plant within 1.8 miles of the site, and a reactor for testing breeder reactor fuels and components within 12 miles of the site. A serious accident at any of these facilities would disrupt repository operations.

The Richton site has several nearby potentially hazardous installations and operations. The Richton Airport is within 3 miles of the site, but the probability of an air crash at the site is extremely low. A portion of the restricted airspace of the DeSoto Military Operations Area is within 5 miles. Future expansion or a more intensive use of the restricted airspace could increase the risk of an airplane crash. A 16-inch underground gas pipeline passes 1 mile from the site, but it does not constitute a credible hazard to a repository. There are two producing oil fields within 3 miles of the site. Explosions or fires at these facilities are unlikely to affect a repository at the site. State Highways 42 and 15 pass within 2 and 3 miles of the site, respectively. These highways could be used for hazardous cargoes. The nearest railroad is more than 12 miles from the Richton site.

The Yucca Mountain site has several nearby hazardous installations and operations, including the underground testing of nuclear devices, an Air Force range, and the Nevada Research and Development Area. Underground testing of nuclear weapons occurs about 10 to 20 times per year at the Nevada Test Site, which is more than 24 miles from Yucca Mountain. Some of this testing might require that underground repository activities be temporarily suspended. The Yucca Mountain site occupies a small portion of the Nellis Air Force Range, which is used for aircraft overflights but not as a target area. The only potential hazard from these overflights is the very remote chance that an airplane carrying ordinance could crash at Yucca Mountain. Research with spent fuel is performed at the Nevada Research and Development Area, which includes a major portion of Yucca Mountain. (The spent fuel is tentatively scheduled for removal in 1986.) However, these research activities are not likely to affect repository operations.

Summary of comparative evaluations

The Davis Canyon and the Richton sites are the most favorable for the guideline on offsite installations and operations. There are no nuclear facilities or other facilities subject to 40 CFR Part 190 or 40 CFR Part 191, Subpart A, located within 50 miles of the Richton site. Potentially hazardous facilities near the site include a major State highway, a gas pipeline, an oil

field, an airport, and restricted airspace associated with Camp Shelby. However, these facilities detract less from a site's favorability than a nearby nuclear installation would. At Davis Canyon, the only potential sources of radioactive emissions in the area of the site are three uranium mills. Radionuclide releases from these facilities would not contribute significantly to releases from a repository. There are no nearby hazardous installations or operations that are likely to pose a credible risk to a repository. The Deaf Smith site is slightly less favorable. The only potential source of radioactive emissions is the Pantex plant, but the contributions from this plant are not expected to be significant. Potentially hazardous installations and operations near the site include a major U.S. Highway. There are no nuclear facilities subject to 40 CFR Part 190 or Part 191, Subpart A, located near the Yucca Mountain site. Nonetheless, several potential sources of radioactivity that reduce its favorability are within 50 miles, including nuclear weapons testing and radioactive-waste disposal. The Hanford site is the least favorable for this guideline: there are potentially hazardous national defense facilities or other facilities subject to 40 CFR Part 190 near the Hanford site that could affect repository operations.

7.3.1.2 Preclosure system guideline for radiological safety

The preclosure system guideline for radiological safety requires that any projected radiological exposures of the general public and any projected releases of radioactive materials to restricted and unrestricted areas during repository operation and closure shall meet the applicable requirements set forth in 10 CFR Part 20, 10 CFR Part 60, and 40 CFR 191, Subpart A. The evidence does not support a finding that any of the sites is not likely to meet this qualifying condition.

The pertinent system elements are (1) the site-specific characteristics that affect radionuclide transport through the surroundings; (2) the engineered components whose function is to control releases of radioactive materials; and (3) the people who, because of their location and distribution in unrestricted areas, may be affected by radionuclide releases. This guideline is assigned the greatest importance among the preclosure system guidelines because it is directed at protecting both the public and the repository workers from exposures to radiation. To provide a comparative context for understanding the evaluation for this preclosure system guideline in Chapter 6, a brief summary of the evaluation of each of the sites with respect to the pertinent system elements is presented below.

With the exception of meteorological conditions, the Davis Canyon site has favorable characteristics for preclosure radiological safety. From an integrated-system viewpoint, atmospheric dispersion conditions that could be poor at times are not likely to prevent compliance with the radiation protection requirements. However, radioactivity releases from a repository are predicted to be small and are expected to more than compensate for the less than favorable atmospheric dispersion. Modeling results indicate that no member of the public is likely to receive an annual whole-body dose of more than 1.3 millirem during the construction period or more than 1.8 millirem

in any year during the operational period. On comparing these values with the regulatory limits (40 CFR Part 191) of 25 millirem per year to the whole body or approximately 140 millirem per year from natural background radiation, it appears that a repository can be located and operated at the Davis Canyon site with insignificant radiological risks to the public.

The Deaf Smith site also has generally favorable characteristics for preclosure radiological safety. A potentially adverse condition is that the dominant wind direction is from the south, and the city of Vega is approximately 8 miles to the north. However, the radioactive releases from the repository are predicted to be very small, and therefore compliance is likely. Modeling results indicate that no member of the public is likely to receive an annual whole-body dose greater than 0.04 millirem during construction or greater than 0.17 millirem in any year from normal operations during the operational period. Comparing these values with the limits of 40 CFR Part 191 (25 millirem per year to the whole body) or with approximately 95 millirem per year from natural background, it appears that a repository at the Deaf Smith site would pose insignificant radiological risks to the public.

The Hanford site has favorable characteristics pertinent to preclosure radiological safety. The meteorological conditions in the area show good atmospheric dispersion and infrequent occurrences of extreme weather. Moreover, there are no permanent residents at the site. Because of the very small radionuclide releases from the repository, the low population density in the surrounding area and the distance from the repository to highly populated areas, routine repository operations would not be expected to exceed the regulatory limits for the exposure of the general public to radiation. The individual radiation doses from other operations in the vicinity of the Hanford Site are greater than that projected for the repository. These doses are monitored and are within applicable Federal standards.

At the Richton Dome, the site characteristics that are pertinent to preclosure radiological safety are generally favorable except for meteorological conditions, which could be poor at times, with occasional stagnant conditions. From an integrated-system viewpoint, these conditions are not likely to prevent compliance with the radiation-protection requirements. Radioactive releases from a repository are predicted to be very small, which would more than compensate for the less-than-favorable atmospheric dispersion conditions. Modeling results indicate that no member of the public is likely to receive an annual whole-body dose greater than 0.41 millirem during the construction period. A comparison with the limits of 40 CFR Part 191 (25 millirem per year to the whole body or approximately 10 millirem per year from natural background radiation), it appears that a repository at the Richton site can be operated without significant radiological risks to the public.

At Yucca Mountain the meteorological characteristics favor the ability of the site to limit exposure to radiation among workers and the public; the distribution of people who live outside the area would also restrict exposures. Estimates of both the extreme worst-case accidental radiological exposures to the general public and the exposures due to normal operation are below the limits specified in 10 CFR Part 20 (1984), 10 CFR Part 60 (1983),

and 40 CFR 191, Subpart A (1985). Estimated releases under normal repository operation (Section 6.4.1) produce radionuclide concentrations that are well below the maximum permissible concentrations.

The evidence does not support a finding that any of the sites is not likely to meet the qualifying condition for preclosure radiological safety.

7.3.2 ENVIRONMENT, SOCIOECONOMICS, AND TRANSPORTATION

7.3.2.1 Technical guidelines

Three technical guidelines are associated with the preclosure system guideline on environmental quality, socioeconomics, and transportation. Their objective is to ensure that the public and the environment are protected from the effects of repository construction, operation, closure, and decommissioning.

7.3.2.1.1 Environmental quality

The qualifying condition for the environmental quality guideline is as follows:

The site shall be located such that (1) the quality of the environment in the affected area during this and future generations will be adequately protected during repository siting, construction, operation, closure, and decommissioning, and projected environmental impacts in the affected area can be mitigated to an acceptable degree, taking into account programmatic, technical, social, economic, and environmental factors; and (2) the requirements specified in §960.5-1(a)(2) can be met.

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-13), four major considerations are identified that influence the favorability of the sites with respect to the qualifying condition. These major considerations are (1) the ability to meet applicable environmental requirements, (2) the ability to mitigate environmental impacts, (3) the absence of protected Federal resource areas as well as threatened and endangered plant and animal species, and (4) the absence of protected State or regional resource areas, Native American resources, and cultural sites. As a group, major considerations 1 and 2 are more important than major considerations 3 and 4, but the factors within each group are considered to be of equal importance.

Evaluation of sites in terms of the to major considerations

Ability to meet applicable environmental requirements. This major consideration addresses the procedural and substantive requirements of environmental regulations with which the repository must comply. It addresses

Table 7-13. Guideline-condition findings by major consideration--
environmental quality^{a,b}

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: ABILITY TO MEET APPLICABLE ENVIRONMENTAL REQUIREMENTS					
Favorable condition 1					
Projected ability to meet, within time constraints, all Federal, State, and local procedural and substantive environmental requirements applicable to the site and the activities proposed to take place thereon.	NP	NP	P	NP	P
Potentially adverse condition 1					
Projected major conflict with applicable Federal, State, or local environmental requirements.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 2: ABILITY TO MITIGATE ENVIRONMENTAL IMPACTS					
Favorable condition 2					
Potential significant adverse environmental impacts to present and future generations can be mitigated to an insignificant level through the application of reasonable measures, taking into account programmatic, technical, social, economic, and environmental factors.	NP	NP	P	NP	P
Potentially adverse condition 2					
Projected significant adverse environmental impacts that cannot be avoided or mitigated.	P	NP	NP	NP	NP
MAJOR CONSIDERATION 3: PROTECTED FEDERAL RESOURCE AREAS					
Potentially adverse condition 3					
Proximity to, or projected significant adverse environmental impacts of the repository or its support facilities on, a component of the National Park System, the National Wildlife Refuge System, the National Wild and Scenic Rivers System, the National Wilderness Preservation System, or National Forest Land.	P	NP	NP	P	NP
Potentially adverse condition 6					
Presence of critical habitats for threatened or endangered species that may be compromised by the repository or its support facilities.	NP	NP	NP	NP	NP

Table 7-13. Guideline-condition findings by major consideration—
environmental quality^{a, b}. (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 4: PROTECTED STATE OR REGIONAL RESOURCE AREAS, NATIVE AMERICAN RESOURCES, CULTURAL SITES					
Potentially adverse condition 4					
Proximity to, and projected significant adverse environmental impacts of the repository or its support facilities on, a significant State or regional protected resource area, such as a State park, a wildlife area, or a historical area.	P	NP	NP	NP	NP
Potentially adverse condition 5					
Proximity to, and projected significant adverse environmental impacts of the repository and its support facilities on, a significant Native American resource, such as a major Indian religious site, or other sites of unique cultural interest.	NP	NP	NP	NP	NP

^a Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

^b Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

applicable site-specific regulations at the Federal, State, and local levels. A site's standing against this consideration is determined by evaluating the degree to which repository activities will comply with requirements as well as the ability to do so within specific time constraints. This consideration relates directly to the qualifying condition and the first favorable and potentially adverse conditions, which address the ability to comply with environmental requirements within time constraints. Because compliance with environmental requirements is a measure of the ability to protect the environment at a site, this consideration is a direct indicator of a site's ability to meet the qualifying condition for environmental quality.. Table 6-2 and Table 6-3 in each EA (Table 6-9 and Table 6-10 in the Yucca Mountain EA) summarize actions that are planned at the sites to ensure they comply with applicable requirements and review their ability to meet each requirement. A summary of the evaluation for each site follows.

The Davis Canyon site is expected to meet all potentially applicable environmental requirements. However, it may not be possible to do so within time constraints because of uncertainties about the time required to obtain certain permits, such as those required under the Utah Air Conservation Act.

The Deaf Smith site is expected to meet all potentially applicable environmental requirements. However, it may not be possible to do so within time constraints because of uncertainties regarding the time required to comply with requirements like the Texas Drilled and Mined Shaft Act.

The Hanford site is an area that has been dedicated to nuclear activities since 1943. The environmental requirements are known for the area, and it is expected that the site will be able to meet the potentially applicable environmental requirements within time constraints.

The Richton and Yucca Mountain sites are expected to meet all potentially applicable environmental requirements, but the Richton site may not do so within time constraints because of uncertainties regarding the time to obtain certain permits.

Ability to mitigate environmental impacts. This consideration evaluates the significance of the environmental impacts of the repository and accounts for the degree to which impacts can be mitigated. It also considers features of the mitigation measures, such as their time requirements and technological feasibility, and the social, economic, or environmental factors that affect their applicability to a particular site. This consideration relates directly to the qualifying condition and the second favorable and potentially adverse conditions, which address the ability to mitigate impacts at each site. Because of its direct relevance to the qualifying condition, the environmental-impact consideration is a direct indicator of a site's ability to meet the qualifying condition for the environmental-quality guideline. A summary of the evaluation for this consideration for each site follows.

It is projected that all potentially significant impacts at the Davis Canyon site can be avoided or mitigated to an acceptable level. However, extensive mitigation measures would be required because of the close proximity of Canyonlands National Park. Although it is projected that all applicable environmental impact standards can be met, some impacts cannot be mitigated to insignificant levels. For example, construction and operation noise will be audible within Canyonlands National Park, and access corridors and facilities

will be visible from the Park. Night-sky glow from project lighting may also be visible within the Park.

It is projected that all potentially significant impacts at the Davis Canyon site can be avoided or mitigated to an acceptable level and all applicable environmental standards can be met. However, extensive mitigation measures would be required because of the close proximity of Canyonlands National Park. Furthermore, some impacts cannot be mitigated to insignificant levels. For example, construction and operation noise will be audible within the Canyonlands National Park, and access corridors and facilities will be visible from the Park. Night skyglow from repository lights may also be visible within the Park.

At the Deaf Smith site, it is projected that all potentially significant impacts can be avoided or mitigated to an acceptable level and that all applicable environmental standards can be met. However, some impacts cannot be mitigated to insignificant levels. For example, about 5,760 acres of farmland will be permanently removed from production.

At the Hanford site, all potentially significant impacts can be avoided or mitigated to insignificant levels. No noise or air-quality impacts are expected outside the boundary of the larger Hanford Site, and no impacts are projected for the Columbia River. Potential impacts associated with offsite developments will be mitigated through siting and engineering measures.

At the Richton site, it is projected that all potentially significant impacts can be avoided or mitigated to an acceptable level, and that all applicable environmental standards can be met. However, some impacts cannot be mitigated to insignificant levels. The repository will be visible, and noise will be audible in offsite areas.

It is projected that all potentially significant impacts at the Yucca Mountain site can be avoided or mitigated to insignificant levels. Air-quality impacts at the controlled-area boundary will be maintained within the limits specified in applicable regulations. Releases of radioactivity from naturally occurring material will increase during the excavation of the underground facility, but they are not expected to be significant.

Protected Federal resource areas. This consideration relates directly to the third and sixth potentially adverse conditions. It addresses the following Federal lands that are identified in these conditions: the National Park System, the National Wildlife Refuge System, the National Wild and Scenic Rivers System, the National Wilderness Preservation System, and National Forest Land, as well as designated critical habitats for threatened or endangered species. The evaluation of sites for this consideration is based on their proximity to, and the degree of projected impacts on, the listed areas, except for critical habitats. Critical habitats are considered on the basis of whether they could be compromised by the repository. Because this consideration addresses the protection of environmental quality in terms of a subset of environmental conditions (i.e., specifically identified resource areas), it is relatively less important in the overall evaluation of sites than the first two considerations. A summary of the evaluation for each site follows.

The repository operations area at the Davis Canyon site is within 1 mile of the eastern boundary of the Canyonlands National Park and is considered to be proximate to the Park. Impacts on the park include increased suspended particulate and nitrogen oxides, increased noise levels, visibility of repository facilities, temporarily disrupted access, and night skyglow. There are no known or designated critical habitats for threatened or endangered species that could be compromised by the repository or its support facilities, although there are crucial riparian habitats.

The Federal resource area nearest to the Deaf Smith site, the Buffalo Lake National Wildlife Refuge, is 22 miles from the site. No significant adverse impacts are projected for this resource. There are no critical habitats for threatened or endangered species within the site or site vicinity that could be compromised by the repository or its support facilities.

The Hanford site is on Federal land not designated for protection. The site is 4 miles from the Saddle Mountains Wildlife Refuge (a multipurpose area of the Hanford Site) and 16 miles from the McNary National Wildlife Refuge. No significant adverse impacts are projected for these wildlife refuges. No federally recognized threatened or endangered species are known to inhabit the Hanford site, though several species (e.g., the bald eagle and the peregrine falcon) have been sighted within the site. Three species of birds that are candidates for designation as threatened or endangered nest within or near the site.

The Richton site is 2.5 miles from the DeSoto National Forest, but no significant adverse impacts are projected for the forest. There are no known or designated critical habitats for threatened or endangered species that could be compromised by the repository or its support facilities.

At the Yucca Mountain site, the northern part of the controlled area is 5 miles from the Timber Mountain Caldera National Natural Landmark, which lies within the Nellis Air Force Range and the Nevada Test Site. The Toiyabe National Forest is about 50 miles from the site, and the Death Valley National Monument is 20 to 25 miles from the site. The rail line to the site will pass within several miles of the Desert National Wildlife Range, parts of which are suitable for inclusion in the Wilderness Preservation System. There are no critical habitats at the Yucca Mountain site. Ash Meadows, which contains several protected species, is about 25 miles away. No significant adverse impacts are projected for any designated Federal lands or protected species.

Protected State or regional resource areas, Native American resources, and cultural sites. This consideration relates directly to the fourth and fifth potentially adverse considerations. The fourth potentially adverse condition identifies three significant State or regionally protected resource areas: State parks, wildlife areas, and historical areas. The fifth potentially adverse condition requires an evaluation of significant Native American resources, such as religious sites, and other sites of unique cultural interest. The evaluation addresses the combined effects of a site's proximity to resource areas and the projected level of impact on those areas. Because this consideration addresses the protection of environmental quality in terms of a subset of environmental conditions (i.e., specific resource areas), it is equal in importance to the third consideration but less important than the first two considerations. A summary of the evaluation for each site follows.

The Newspaper Rock State Historical Monument is near Utah State Highway 211, 17 miles from the Davis Canyon site. The petroglyph panel at Newspaper Rock is a significant cultural resource and is listed on the National Register of Historic Places. The increased traffic flow past the Monument that would be associated with a repository at Davis Canyon will disrupt some visitation and overnight camping at the Monument. The nearest State park is the Dead Horse State Park, which is 30 miles away. The nearest significant Native American resource or site of unique cultural interest is the Salt Creek Archaeological District, which lies along the eastern edge of the Canyonlands National Park. Impacts of the repository and support facilities on these resources are not expected to be significant.

The State protected resource nearest to the Deaf Smith site is the Palo Duro Canyon State Park, located 44 miles away. Since no significant State, regional, or Native American resources are known to be present in the area of the site, no significant adverse impacts are expected.

A repository at the Hanford site would not affect any protected resource area. There are no known significant State, regional, or Native American resources within or adjacent to the site. There are significant Native American resources along the shorelands of the Columbia River, 4 miles from the site, but no significant adverse impacts are projected for these resources.

The nearest State or regionally protected resource to the Richton site is the Paul E. Johnson State Park, which is 20 miles away. The park is not expected to experience any significant adverse impacts. There are no significant Native American resources or cultural sites recorded at the Richton site, and the potential for discovering such resources is considered low.

The Yucca Mountain site is not located near any State or regionally protected resource area. The rail corridor that would be constructed to the site is not projected to adversely affect any resource areas, although it will pass within 0.9 mile of the F. R. Lamb State Park. Most of the Yucca Mountain site has been surveyed for cultural artifacts. Limited investigations have identified 178 prehistoric and 6 historic sites, many of which consist of scattered debris. No major impacts are projected for any significant Native American resource or unique cultural site.

Summary of comparative evaluation

The Hanford and the Yucca Mountain sites are most favorable under the environmental-quality guideline. Both sites are expected to meet all major environmental requirements within time constraints. Adverse environmental impacts at both sites can be avoided or mitigated to insignificant levels. Since these sites are not near any protected Federal, State, or regionally protected resource, or near any significant Native American resource or site of unique cultural interest, the development of a repository at either of these sites is not projected to have significant impacts on any of these resources.

The Deaf Smith site can comply with all potentially applicable environmental requirements, but may not be able to do so within time constraints. Similarly, it is projected that adverse impacts at the site can be limited to acceptable, but not insignificant, levels. The Deaf Smith site

is favorable with regard to the third (protected Federal resource areas) and the fourth (protected State or Native American resources) major considerations because the site is not near any of the relevant resource areas and would not be expected to adversely impact such areas.

The Richton site is also expected to meet all applicable environmental requirements, although it may not be able to do so within time constraints. All adverse impacts at the site can be avoided or mitigated, but not to insignificant levels. The Richton site is less favorable than the Hanford, Yucca Mountain, and Deaf Smith sites with respect to protected Federal resource areas because of its proximity to the DeSoto National Forest. The Richton site is favorable with regard to the fourth consideration (protected State or Native American resources) because a repository at this site is not projected to cause adverse impacts on any State or regionally protected resource area, significant Native American resource, or site of unique cultural interest.

The Davis Canyon site is the least favorable for the environmental-quality guideline. It is projected that all potentially applicable environmental requirements can be met, but it may not be possible to do so within time constraints. It is also projected that adverse impacts can be mitigated to acceptable but not insignificant levels. The favorability of the Davis Canyon site is further reduced by its proximity to, and potential impacts on, the Canyonlands National Park and the Newspaper Rock State Historical Monument.

7.3.2.1.2 Socioeconomic impacts

The qualifying condition for the socioeconomics guideline is as follows:

The site shall be located such that (1) any significant adverse social and/or economic impacts induced in communities and surrounding regions by repository siting, construction, operation, closure, and decommissioning can be offset by reasonable mitigation or compensation, as determined by a process of analysis, planning, and consultation among the DOE, affected State and local government jurisdictions, and affected Indian Tribes; and (2) the requirements specified in 960.5-1(a)(2) can be met.

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-14), six major considerations are identified that influence the favorability of the sites with respect to the qualifying condition. These major considerations are (1) potential impacts on community services and housing, (2) potential impacts on direct and indirect employment and business sales, (3) potential impacts on primary sectors of the economy, (4) potential impacts on the revenues and expenditures of public agencies, (5) the need to purchase or acquire water rights that could affect development in the area, and (6) potential social impacts. No order of importance is assigned to these six considerations. Each consideration is, in turn, influenced by a number of more-specific conditions or contributing factors, which are discussed below.

Table 7-14. Guideline-condition findings by major consideration--socioeconomics^{a, b}

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: POTENTIAL IMPACTS TO COMMUNITY SERVICES AND HOUSING					
Favorable condition 1					
Ability of an affected area to absorb the project-related population changes without significant disruptions of community services and without significant impacts on housing supply and demand.	NP	P	P	P	P
Potentially adverse condition 1					
Potential for significant repository-related impacts on community services, housing supply and demand, and the finances of State and local government agencies in the affected area.	P	NP	NP	NP	NP
MAJOR CONSIDERATION 2: POTENTIAL IMPACTS ON DIRECT AND INDIRECT EMPLOYMENT AND BUSINESS SALES					
Favorable condition 2					
Availability of an adequate labor force in the affected area.	NP	NP	NP	NP	NP
Favorable condition 3					
Projected net increases in employment and business sales, improved community services, and increased government revenues in the affected area.	P	P	P	P	P
Potentially adverse condition 2					
Lack of an adequate labor force in the affected area.	P	P	P	P	P
MAJOR CONSIDERATION 3: POTENTIAL IMPACTS TO PRIMARY SECTORS OF THE ECONOMY					
Favorable condition 4					
No projected substantial disruption of primary sectors of the economy of the affected area.	P	P	P	P	P
Potentially adverse condition 4					
Potential for major disruptions of primary sectors of the economy of the affected area.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 4: POTENTIAL IMPACTS TO THE REVENUES AND EXPENDITURES OF PUBLIC AGENCIES					
Favorable condition 3					
Projected net increases in employment and business sales, improved community services, and increased government revenues in the affected area.	P	P	P	P	P

Table 7-14. Guideline-condition findings by major consideration--
socioeconomics^{a, b} (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 4: POTENTIAL IMPACTS TO THE REVENUES AND EXPENDITURES OF PUBLIC AGENCIES (Continued)					
Favorable condition 3 (continued)					
Potentially adverse condition 1					
Potential for significant repository- related impacts on community services, housing supply and demand, and the finances of State and local government agencies in the affected area.	P	NP	NP	NP	NP
MAJOR CONSIDERATION 5: THE NEED TO PURCHASE OR ACQUIRE WATER RIGHTS THAT COULD EFFECT DEVELOPMENT IN THE AREA					
Potentially adverse condition 3					
Need for repository-related purchase or acquisition of water rights, if such rights could have significant adverse impacts on the present or future development of the affected area.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 6: POTENTIAL SOCIAL IMPACTS					
Favorable condition 1					
Ability of an affected area to absorb the project-related population changes without significant disruptions of community services and without significant impacts on housing supply and demand.	NP	P	P	P	P
Potentially adverse condition 1					
Potential for significant repository-related impacts on community services, housing, supply and demand, and the finances of state and local government agencies in the affected area.	P	NP	NP	NP	NP

^a Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the
favorable or potentially adverse condition is not present at the site; P = for the purpose of
this comparative evaluation, the favorable or potentially adverse condition is present at the site.

^b Analyses supporting the entries in this table are presented in Chapter 6 of the
environmental assessment for each site.

Evaluation of the sites in terms of the major considerations

Potential impacts on community services and housing. This consideration relates to the requirement in the qualifying condition that impacts on community services or housing in affected areas and communities can be mitigated or compensated for. This consideration is derived from the first favorable condition and the first potentially adverse condition. The first favorable condition focuses on the ability of the affected area to absorb repository-related population growth without disrupting community services and the supply and demand for housing. The potentially adverse condition addresses impacts on community services and housing in communities near a potential site. Impacts on community services and housing depend on five contributing factors: population composition and density, the distribution of in-migrants, current capacity and trends in the use of community services and infrastructure, housing supply and demand, and the community's ability to accommodate growth. A site's favorability improves as the combination of these contributing factors leads to fewer impacts on community services and housing. A summary of the evaluation for each site follows.

A repository at the Davis Canyon site is likely to result in substantial impacts on community services and housing in the affected area. The projected net change in the population of Grand and San Juan Counties is expected to be approximately 20 percent above the baseline population during the peak of in-migration. This level of population increase may cause a significant disruption in housing and community services. The number of housing units needed by repository-related households could reach 1,600 units. Fewer than half this number of units are currently available in the study area. The communities of Moab, Monticello, and Blanding are projected to have peak-year cumulative growth rates of 31, 50, and 24 percent, respectively. Although this level of growth would occur over a 6-year period, it would cause significant impacts.

The development of a repository at the Deaf Smith site is not expected to result in major impacts to community services or housing. Most project in-migrants are expected to locate in Amarillo, about 40 miles from the site. Amarillo is a large urban center that has a sufficient community infrastructure to accommodate repository workers and their families. Vega, which is the closest community to the site, is projected to experience a peak-year cumulative growth of 8 percent. Since this growth would occur over a 6-year period, it is not considered to have potential for significantly disrupting the community. However, in-migration is expected to cause some minimal increase in the demand for community services (e.g., housing, schools, police protection, medical services, water supply, and recreation) in the affected area.

The Tri-Cities (Richland, Kenewick, and Pasco) have historically received most of the in-migrating work force associated with large projects at the Hanford Site. If the most likely estimate of 1,700 in-migrants for the repository is used, annual growth rates during the peak year would be less than 4 percent for all communities. These annual growth rates are low in comparison with previous levels of growth in the area. There is also a large and underused infrastructure, particularly excess housing, in the Tri-Cities area. This suggests that the development of a repository at Hanford represents an opportunity for the area to more fully use its resources. Therefore, community-services and housing impacts are projected to be favorable.

For the Richton site, the capacity of housing in counties receiving in-migrants is expected to be adequate. Because the availability of community services generally parallels the availability of housing, these services are also expected to be adequate in the affected area. At a community level, the town of Richton is projected to experience a peak-year cumulative growth of 37 percent. This growth would occur over a 4-year period. Although the average annual growth rate is higher than the 6-percent growth rate projected for Richton's baseline population, significant disruption is not expected. Nonetheless, the in-migrating population is projected to cause moderate service impacts in the study area, including the need for some additional housing, teachers, police officers, physicians, hospital beds, and water and sewage facilities.

For the Yucca Mountain site, over 80 percent of the in-migrants are expected to settle in the Los Vegas area, where the infrastructure is sufficient to accommodate them. In the rural communities closer to the site, the maximum 1-year growth rates, which are projected from the historical settlement patterns of workers at the Nevada Test Site, will be less than 5 percent for all communities near the site except Pahrump (5 percent) and Indian Springs (13.2 percent). Although demands for services and housing in communities could increase in proportion to these peak 1-year growth rates, the potential impacts would be largely confined to the service providers that are best equipped for dealing with growth. Generally, services in the unincorporated communities near the site (i.e., Indian Springs, Pahrump, Beatty, and Amargosa Valley) are provided not by town governments but by county-wide agencies that have broad tax bases, planning capabilities, and experience in responding to population growth rates within the range of those projected for the repository. With only a few exceptions, water in the unincorporated communities near the repository site is supplied by private wells, and waste water is disposed of in private septic tanks and leach fields. In addition, housing in rural southern Nevada is provided almost entirely by the private sector.

Potential impacts on direct and indirect employment and business sales. This major consideration is derived from the second and the third favorable conditions and the second potentially adverse condition. Two factors contribute to the potential for increased direct and indirect employment and business sales: repository-related needs for labor and expected local hires, and repository-related local purchases of materials. This major consideration is related to the qualifying condition in that increased local employment and business sales enhance the ability of affected areas and communities to absorb repository-related growth by increasing business and tax revenues. A site's favorability increases with repository-related economic growth. A summary of the evaluation for each site follows.

At the Davis Canyon site, a repository is expected to generate over 2,000 direct and indirect jobs at its peak, of which about 400 are expected to be filled by local residents. The repository is also expected to generate about \$5.4 million per year in local purchases during the construction phase.

At the Deaf Smith site, local residents are expected to fill 1,380 of the total number of jobs at the peak of repository development. Direct local purchases of about \$11.3 million per year are projected during repository construction. An additional \$5.7 million per year is expected to be spent as a result of indirect effects caused by material purchases.

At the Hanford site, total employment could increase by more than 2,400 at the peak of repository development. A substantial number of these jobs will be filled locally. In addition, substantial spending through wages and on purchases of materials from local suppliers is expected.

At the Richton site, the repository is expected to generate about 1,300 jobs for local residents at the peak of its development. In addition, about \$5.3 million in direct local material purchases will be made during repository construction.

For the Yucca Mountain site, up to 4,800 jobs could be created during peak repository development. Many of these jobs are expected to be filled by current residents of the area. The increases in area income from wages for repository construction and operation could reach \$110 million in 1998.

Potential impacts on primary sectors of the economy. The third major consideration is derived from the fourth favorable condition and fourth potentially adverse condition. The contributing factors are major sectors of the economy, employment distribution and trends by economic sector, and the compatibility of a repository with the area's economic base. The smaller any projected disruption, the greater the site's favorability. A summary of the evaluation for each site follows.

Primary sectors of the Davis Canyon study area are retail trade and services (31 percent of employment), government (24 percent of employment), and mining (14 percent of employment). Since unemployment in mining has increased significantly in the last 6 years, a repository may have a positive effect on this sector. The extent of this positive effect is unknown, because significant numbers of miners have left the area since 1983. The demands on local government created by new growth should create jobs in the government sector. In retail trade and services, tourism represents approximately 475 man-years of employment for San Juan and Grand Counties or about 24 percent of the jobs in these sectors. Because the Canyonlands National Park is near the repository, some tourists may choose to avoid the park, and some jobs related to tourism could be lost. The total number of jobs directly associated with purchases made by tourists with Canyonlands as their primary destination is approximately 76 man-years of employment. The local retail-and-service jobs directly related to local purchases associated with the repository will average 240 man-years of employment during construction and 230 man-years during operation. Therefore, while some tourism-related jobs in the retail and service sectors may be lost, other jobs are expected to be created.

The primary sectors of the Deaf Smith study area are government (18 percent), retail trade (15 percent), services (14 percent), agriculture (10 percent), and manufacturing (10 percent). It is expected that the repository will increase the need for products and services provided by the retail trade, government, and service sectors. No substantial loss of employment due to the repository is expected for the agricultural or manufacturing sectors because most of their markets are outside the region of the site. However, the sales of health foods and bottled water could decline. In addition, projected impacts on the agricultural sector include a loss of more than \$1.6 million in crop and livestock revenues at the peak of construction (about 0.12 percent of the expected crop and livestock revenues in the region in 1997); a loss of \$1.7 million in crop and livestock revenues at the peak of operation; a loss of \$2.5 million and \$3.0 million in agricultural business during the peak of

repository construction and operation, respectively; and a loss of 0.61 percent of the productive land in Deaf Smith County.

In the affected area of the Hanford site, the potential for major disruptions of primary sectors of the economy is very small. The primary sectors of employment are the Washington Public Power Supply System and its contractors, the DOE and its contractors, and agriculture. A repository at the Hanford site would probably stabilize economic conditions and employment in the area.

In the affected area of the Richton site, the primary economic sectors are manufacturing (21 percent), government (25 percent), and retail trade (22 percent). The repository is not expected to affect markets for manufactured goods. Employment in the trade and government sectors is likely to increase because of increases in wages, local purchases, business sales, and demands for services.

The primary sectors of the economy in southern Nevada are mining and tourism. A repository at Yucca Mountain is expected to increase the number of mining jobs in Nye County. In regard to tourism, even though repository-related increases in population may have a small positive effect, only potential negative impacts have been investigated to date. Preliminary results of an ongoing evaluation are inconclusive. Studies of the effects of well-publicized accidents have yielded no evidence of long-term effects on tourism.

Potential impacts on public agency revenues and expenditures. This consideration is derived from the third favorable condition and the first potentially adverse condition, which addresses the potential for increased revenues, and the net fiscal balances of State and local government agencies, respectively. This consideration relates to the qualifying condition in that the DOE must be able to mitigate adverse economic impacts, including impacts on the finances of State or local governments. Impacts on the revenues and expenditures of public agencies depend on three contributing factors: the sources of, and trends in, the expenditures and revenues of local government; the additional needs for community services induced by the repository project; and economic growth in the area and resulting increases in tax revenues. A site's favorability increases as the repository more positively affects State and local finances and decreases as more mitigation of fiscal impacts is required. A summary of the evaluation for each site follows.

At the Davis Canyon site, a repository will increase the revenues collected through property taxes, sales taxes, and user fees. These increases in revenues, however, may not offset increases in outlays for community services and infrastructure needs.

At the Deaf Smith site, the repository will also increase the revenues collected in property taxes, sales taxes, and user fees. These increases in revenues are expected to offset the projected minimal impacts on community services.

At the Hanford site, the State or local governments will not experience significant adverse fiscal impacts. There are virtually no projected impacts

on community services, and there are some economic benefits that will result in additional tax revenues.

The potential impact on the revenues and expenditures of public agencies affected by the Richton site is similar to that at the Deaf Smith site. Revenues from property taxes, sales taxes, and user fees are likely to increase. These revenue increases are expected to offset increases in expenditures due to changes in service requirements.

At the Yucca Mountain site, significant repository-induced expenditures are expected to result in increased State and local tax revenues, which may be offset by additional outlays in the study area.

Need to purchase or acquire water rights that could affect development in the area. This major consideration is derived from the third potentially adverse condition (see Table 7-14). The need to acquire water rights depends on two contributing factors: project-related water requirements and current water rights, use, and capacity. Specifically, the greater the competition for water at the site and the more the DOE's acquisition of water rights could affect development in the area, the lower the site's favorability. A summary of the evaluation for each site follows.

At the Davis Canyon site there is a variety of potential water sources. A likely source of water is the San Juan County Water Conservatory District, which has jurisdiction over the site. The Conservatory District has indicated that it would enter into an agreement for the annual sale or lease of up to 2,800 acre-feet of water from the Colorado River or one of its tributaries during construction and up to 500 acre-feet during the operation of the repository. Because the San Juan Planning Council expects that two new reservoirs that are being built in the Blanding and Monticello area will supply enough water for future needs and because the Council is willing to sell or lease part of its own appropriation, development in the area should not be affected.

The Ogallala aquifer, the major source of water for municipal use and irrigation in the Texas Panhandle and in the area of the Deaf Smith site, is being depleted. The Texas Water Commission predicts that only part of the projected water requirements for irrigated agriculture in 1990 will be met under a high-demand scenario. Although a repository at the Deaf Smith site will require relatively little water to operate in comparison with other industrial users in Texas and less than one-fourth of one percent of projected water supply in the County throughout the life of the repository, the water requirements of the repository will further deplete the aquifer and may compete with other users, especially agricultural users. Municipal and industrial water requirements are expected to be met because these users are able to pay the higher prices associated with more a limited supply.

The Federal Government already owns the water rights that are needed for a repository at the Hanford site. Water will be supplied from the Columbia River by an existing pump station. No significant impacts on municipal water systems in the study area are expected because there is excess capacity in the Tri-Cities area, where most in-migrants would live.

At the Richton site, the DOE will not need to acquire water rights because ground water is expected to be available at the site. In addition, no planned developments in the study area have been identified that would be adversely affected by the water use projected for the repository.

It is projected that sufficient water for a repository at Yucca Mountain can be obtained from new or existing wells at the Nevada Test Site, for which the DOE has existing water rights. For local water systems, secondary impacts due to the increased demand associated with population increases are expected to be minimal, although some communities may require mitigation assistance to expand their water systems to meet the needs of new in-migrants. There are no major developments or population centers that will compete with the repository for ground water. The Las Vegas Valley is projected to have water-supply problems by the year 2020 with or without the population increases resulting from the development of the repository.

Potential social impacts. This major consideration relates directly to the requirement in the qualifying condition that significant social impacts on communities and surrounding areas can be offset by reasonable mitigation or compensation. It also relates to the first favorable and potentially adverse conditions, which address the quality of life by focusing on impacts to community services and the finances of State and local government agencies. Three factors contribute to the potential for social impacts: the quality of life and existing social problems in the affected communities, the size of the in-migrating population in comparison with the existing population, and the compatibility of the in-migrating population with the lifestyles and characteristics of the current residents. The more compatible the in-migrating population with the current population and the fewer the disruptions that it causes, the greater the site's favorability. A summary of the evaluation for each site follows.

At the Davis Canyon site, it is estimated that Moab and Blanding will experience an increase of 31 and 24 percent, respectively, in population during the first 6 years of the repository. Monticello is expected to grow by about 50 percent during the same period. These increases would be dramatic and could lead to conflicts between long-time residents and newcomers over leadership positions. Rapid growth could also contribute to increases in alcohol and drug abuse, crime, and family conflict.

At the Deaf Smith site, Vega is expected to receive an 8-percent increase above the baseline population. On the basis of this population increase, Vega could experience some social changes. The lifestyles of construction workers may not be compatible with long-time residents, though most workers are expected to live in Amarillo or Hereford. Major conflicts over leadership positions between long-term residents and newcomers are not expected.

At the Hanford site, a repository will make a small but positive contribution to the recovery of the area from the decline of the early 1980s. The effect of any impacts on social conditions is likely to be positive. Since expected in-migrating work force is small in comparison with the projected baseline population, serious social disruptions are unlikely. The Yakima Indian Nation, the Confederated Tribes of the Umatilla Indian Reservation, and the Nez Perce Tribe are formally designated as affected

Indian Tribes under the Act. A repository at Hanford is not expected to cause significant social impacts on these Indian Tribes.

At the Richton site, the town of Richton is expected to receive 483 repository-related in-migrants, a 37-percent change over baseline projections for the peak year of construction. This repository-related growth for Richton is significant and will probably cause social changes and conflicts over leadership positions in the community.

For the Yucca Mountain site, most of the in-migrating population is projected to be absorbed in Clark County. Since the size of the in-migrating population is small in comparison with the projected baseline population, and the existing social structure in urban Clark County is highly diverse, the growth-related effects on social structure are not expected to be significant. In contrast, Nye County is a rural area where experience with large energy-development projects indicates that growth-related social disruptions could occur. However, preliminary assessments suggest that in-migrating construction workers would be assimilated within the existing social structure. Historically, communities in Nye County have had a large population of miners, and mining continues to be important in the area. Therefore, because of the diversity of existing cultural environments within Nye and Clark Counties, in-migrating workers would be able to select a compatible cultural environment and are likely to be readily assimilated into the community.

Summary of comparative evaluations

The Hanford site is the most favorable for all six major considerations. The Tri-Cities has a large and under-used infrastructure, and the area would benefit from repository-related employment and increases in business sales. The economy of the affected area is largely based on nuclear activities, although there is also substantial agriculture. No significant adverse fiscal or social impacts are expected, and the DOE owns all necessary water rights.

At the Yucca Mountain site, most of the in-migrants are expected to settle in the area of Las Vegas, which has a sufficient infrastructure to accommodate them. Services in the unincorporated communities nearer the site are generally provided by county-wide organizations that are well equipped to deal with growth. Both Nye and Clark Counties are expected to benefit from increased employment and business sales. Employment in the mining industry in Nye County is expected to increase substantially. The tourist industry is not expected to be negatively affected. Public revenues will probably increase, and social impacts are expected to be small. Sufficient water for the repository can be obtained from wells at the Nevada Test Site, and secondary impacts should be minimal.

At the Deaf Smith site, population growth may cause minimal adverse impacts on community services. Vega could also experience social changes because the lifestyles of newcomers and long-time residents may be incompatible. In addition, a repository is expected to cause minor disruption to the agricultural industry in the affected area. Some water may also be diverted from other uses because the DOE will need to acquire water rights in a region where the major source of water is being depleted. The area is expected to benefit from increased employment, business sales, and tax revenues.

At the Richton site, moderate impacts on community services are projected because of the population growth associated with a repository. Local purchases and job opportunities will increase, but adverse social impacts could occur, especially in the town of Richton. Primary sectors of the economy are not expected to be disrupted, and public revenues should increase. There is no need for the DOE to purchase or acquire water rights.

A repository at the Davis Canyon site is expected to induce major adverse impacts on community services and housing; these impacts will occur in San Juan County and in three small communities near the Davis Canyon site. In addition, a significant population growth may cause substantial social impacts. Although a small number of jobs related to tourism in the retail and service sectors may also be lost, net local employment, business sales, and tax revenues should increase. Water rights are likely to be obtained from the San Juan Planning Council without affecting present or future development.

7.3.2.1.3 Transportation

The qualifying condition for the transportation guideline is as follows:

The site shall be located such that (1) the access routes constructed from existing local highways and railroads to the site (i) will not conflict irreconcilably with the previously designated use of any resource listed in 960.5-2-5(d)(2) and (3); (ii) can be designed and constructed using reasonably available technology; (iii) will not require transportation system components to meet performance standards more stringent than those specified in the applicable DOT and NRC regulations, nor require the development of new packaging containment technology; (iv) will allow transportation operations to be conducted without causing an unacceptable risk to the public or unacceptable environmental impacts, taking into account programmatic, technical, social, economic, and environmental factors; and (2) the requirements of Section 960.5-1(a)(2) can be met.

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-15), four major considerations are identified that influence the favorability of sites with respect to the qualifying condition. These major considerations, in order of decreasing importance, are (1) transportation safety, (2) potential for environmental disruption, (3) the cost of transportation infrastructure, and (4) the cost of transportation hardware and operations. Each of the major considerations is, in turn, influenced by several contributing factors, which are discussed below.

Evaluation of the sites with respect to major considerations

Transportation safety. Transportation to the repository will present a potential hazard, albeit small, to people living along the routes traveled. The hazards are both radiological (i.e., due to the radiological nature of the cargo) and nonradiological (i.e., due to the movement of the transport vehicle and not related to the character of the cargo). The guidelines emphasize that

Table 7-15. Guideline-condition findings by major consideration—transportation^{a, b}

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: THE SAFETY OF TRANSPORTING SPENT FUEL AND HIGH-LEVEL WASTE TO THE REPOSITORY					
Favorable condition 1	NP	P	P	P	P
Availability of access routes from local existing highways and railroads to the site which have any of the following characteristics:					
(i) Such routes are relatively short and economical to construct as compared to access routes for other comparably siting options.	NP	NP	P	NP	NP
(iv) Such routes are free of sharp curves or steep grades are not likely to be affected by landslides or rock slides.	NP	P	P	P	P
(v) Such routes bypass local cities and towns.	NP	P	P	NP	P
Favorable condition 2	NP	P	P	NP	P
Proximity to local highways and railroads that provide access to regional highways and railroads and are adequate to serve the repository without significant upgrading or reconstruction.					
Favorable condition 4	NP	NP	NP	NP	P
Availability of a regional railroad system with a minimum number of interchange points at which train crew and equipment changes would be required.					
Favorable condition 5	NP	NP	NP	P	NP
Total projected life-cycle cost and risk for transportation of all wastes designated for the repository site which are significantly lower than those for comparable siting options, considering locations of present and potential sources of waste, interim storage facilities, and other repositories.					
Favorable condition 8	P	P	P	P	P
Plans, procedures, and capabilities for response to radioactive waste transportation accidents in the affected State that are completed or being developed.					
Favorable condition 9	P	P	P	P	P
A regional meteorological history indicating that significant transportation disruptions would not be routine seasonal occurrences.					

Table 7-15. Guideline-condition findings by major consideration--
transportation^{a, b} (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: THE SAFETY OF TRANSPORTING SPENT FUEL AND HIGH-LEVEL WASTE TO THE REPOSITORY (Continued)					
Potentially adverse condition 2	P	NP	NP	NP	NP
Terrain between the site and existing local highways and railroads such that steep grades, sharp switchbacks, rivers, lakes, landslides, rock slides, or potential sources of hazard to incoming waste shipments will be encountered along access routes to the site.					
Potentially adverse condition 3	P	NP	NP	NP	NP
Existing local highways and railroads that could require significant re-construction or upgrading to provide adequate routes to the regional and national transportation system.					
Potentially adverse condition 4	P	NP	NP	NP	P
Any local condition that could cause the transportation-related costs, environmental impacts, or risk to public health and safety from waste transportation operations to be significantly greater than those projected for other comparable siting options.					
MAJOR CONSIDERATION 2: THE AMOUNT AND NATURE OF THE ENVIRONMENTAL DISRUPTION CAUSED BY DEVELOPING THE TRANSPORTATION NETWORK AND ACCESS ROAD (INFRASTRUCTURE) AROUND AND TO THE SITE					
Favorable condition 1	NP	P	P	P	P
Availability of access routes from local existing highways and railroads to the site which have any of the following characteristics:					
(i) Such routes are relatively short and economical to construct as compared to access routes for other comparable siting options.	NP	NP	P	NP	NP
(iii) Cuts, fills, tunnels, or bridges are not required.	NP	NP	P	NP	NP
(iv) Such routes are free of sharp curves or steep grades and are not likely to be affected by landslides or rock slides.	NP	P	P	P	P
(v) Such routes bypass local cities and towns.	NP	P	P	NP	P
Favorable condition 2	NP	NP	P	NP	P
Proximity to local highways and railroads that provide access to regional highways and railroads, and are adequate to serve the repository without significant upgrading or reconstruction.					

Table 7-15. Guideline-condition findings by major consideration--
transportation^{a, b} (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 2: THE AMOUNT AND NATURE OF THE ENVIRONMENTAL DISRUPTION CAUSED BY DEVELOPING THE TRANSPORTATION NETWORK AND ACCESS ROAD (INFRASTRUCTURE) AROUND AND TO THE SITE (Continued)					
Favorable condition 3	NP	P	P	P	P
Proximity to regional highways, mainline railroads, or inland waterways that provide access to the national transportation system.					
Potentially adverse condition 3	P	NP	NP	NP	NP
Existing local highways and railroads that could require significant re- construction or upgrading to provide adequate routes to the regional and national transportation system.					
Potentially adverse condition 4	P	NP	NP	NP	P
Any local condition that could cause the transportation-related costs, environmental impacts, or risk to public health and safety from waste transportation operations to be significantly greater than those projected for other comparable siting options.					
MAJOR CONSIDERATION 3: THE COST OF DEVELOPING AN ADEQUATE INFRASTRUCTURE BETWEEN THE SITE AND THE NEAREST NATIONAL TRANSPORTATION NETWORK					
Favorable condition 1	NP	P	P	P	P
Availability of access routes from local existing highways and railroads to the site which have any of the following characteristics:					
(i) Such routes are relatively short and economical to construct as compared to access routes for other comparable siting options.	NP	N P	P	NP	NP
(ii) Federal condemnation is not required to acquire rights-of-way for the access routes.	NP	NP	P	NP	NP
(iii) Cuts, fills, tunnels, or bridges are not required.	NP	NP	P	NP	NP
(iv) Such routes are free of sharp curves or steep grades and are not likely to be affected by landslides or rock slides.	NP	P	P	P	P
(v) Such routes bypass local cities and towns.	NP	P	P	NP	P

Table 7-15. Guideline-condition findings by major consideration--
transportation^{a, b} (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 3: THE COST OF DEVELOPING AN ADEQUATE INFRASTRUCTURE BETWEEN THE SITE AND THE NEAREST NATIONAL TRANSPORTATION NETWORK (Continued)					
Favorable condition 2 Proximity to local highways and railroads that provide access to regional highways and railroads, and are adequate to serve the repository without significant upgrading or reconstruction.	NP	NP	P	NP	P
Potentially adverse condition 1 Access routes to existing local highways and railroads that are expensive to construct relative to comparable siting options.	P	P	NP	P	P
Potentially adverse condition 3 Existing local highways and railroads that could require significant re-construction or upgrading to provide adequate routes to the regional and national transportation system.	P	NP	NP	NP	NP
Potentially adverse condition 4 Any local condition that could cause the transportation-related costs, environmental impacts, or risk to public health and safety from waste transportation operations to be significantly greater than those projected for other comparable siting options.	P	NP	NP	NP	P
MAJOR CONSIDERATION 4: THE COSTS ASSOCIATED WITH TRANSPORTING THE SPENT FUEL AND HIGH-LEVEL WASTES TO THE SITE					
Favorable condition 4 Availability of a regional railroad system with a minimum number of interchange points at which train crew and equipment changes would be required.	NP	NP	NP	NP	P
Favorable condition 5 Total projected life-cycle cost and risk for transportation of all wastes designated for the repository site which are significantly lower than those for comparable siting options, considering locations of present and potential sources of waste, interim storage facilities, and other repositories.	NP	NP	NP	P	NP
Favorable condition 6 Availability of regional and local carriers-truck, rail, and waste-which have the capability and are willing to handle waste shipments to the repository.	P	P	P	P	P

Table 7-15. Guideline-condition findings by major consideration--
transportation^{a, b} (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 4: THE COSTS ASSOCIATED WITH TRANSPORTING THE SPENT FUEL AND HIGH-LEVEL WASTES TO THE SITE (Continued)					
Favorable condition 7					
Absence of legal impediment with regard to compliance with Federal regulations for the transportation of waste in or through the affected State and adjoining States.					
Favorable condition 9	P	P	P	P	P
A regional meteorological history indicating that significant transpor- tation disruptions would not be routine seasonal occurrences.					

^a Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the
favorable or potentially adverse condition is not present at the site; P = for the purpose of
this comparative evaluation, the favorable or potentially adverse condition is present at the site.

^b Analyses supporting the entries in this table are presented in Chapter 6 of the
environmental assessment for each site.

the people living near the site will be most significantly affected, but they also recognize that the hazards and impacts of transporting wastes are national in scope. Because the DOE's main goal in transportation is safety, and the guidelines emphasize the role of safety, transportation safety is the most important consideration in evaluating the sites.

The transportation of radioactive materials during the past 40 years has been accomplished with an exemplary record of safety. Models that are used to estimate the radiological risks of transportation tend to generate extremely low expected-risk values for the public because they rely on historical data. When relative terms like "high" or "moderate" are used in this evaluation, they must be considered in the context of the low overall radiological risk from transportation. The nonradiological risk is calculated under the assumption that the probability of accidents for radioactive-waste shipments can be represented by accident statistics for general commerce. The DOE believes that these accident statistics will overestimate the actual number of deaths and injuries. Other factors being equal, the site with the smallest radiological hazard will also have the smallest nonradiological hazard.

Since the principal contributing factor in determining risk is the distance traveled, a better site for this consideration is one that is close to the sources of spent fuel and high-level waste. Other contributing factors that increase the favorability of sites are access and local routes that avoid population centers, flat local terrain with good visibility, and regional weather conditions that rarely cause hazardous road conditions. It should be noted that, regarding weather conditions, the DOE needs additional information before determining the comparative favorability of the sites. In contrast, less favorable sites are distant from waste sources, must be reached by routes that pass through population centers or rugged terrain, and are located in regions where weather conditions often cause hazardous road conditions. A summary of transportation risk and cost calculations is presented in Table 7-16; the reader is referred to Appendix A for more-extensive analytical results. Table 7-17 presents the factors used to evaluate disruptions of the environment and the cost of infrastructure. A summary of the evaluation for each site follows.

Davis Canyon is centrally located in the large region defined by the five nominated sites, but it is more difficult to reach because of its remote and rugged setting. Access from existing highways and railroads is extremely difficult, and there is a potential for landslides that could interrupt or jeopardize shipments. A long stretch of noninterstate highway must be traversed before reaching the site. From a national perspective, the relative risk of transporting to Davis Canyon is moderate to high, but that risk has to be considered along with the potential hazards near the site that could further reduce the overall level of safety. However, the added risk associated with hazardous local access to the site is somewhat offset by the remoteness of the site and the low population density in the area.

The Deaf Smith site is convenient to major national highways. The distance from sources of spent fuel is low to moderate, and, as shown in Table 7-16, the level of relative safety is therefore moderate to high. The terrain surrounding the site is generally flat and poses no safety hazard. The population density around the site is low to moderate.

Table 7-16. Summary of transportation risks and costs

Parameters	Davis Canyon	Deaf Smith	Hanford	Richton	Yucca Mountain
Risk^a					
100% truck					
Radiological	9.5	7.9	12	6.3	11
Nonradiological	30	24	39	19	36
100% rail					
Radiological	0.3	0.2	0.3	0.2	0.3
Nonradiological	2.6	2.1	3.2	1.8	3.0
Number of interchanges	3	2-4	2-4	2-4	1-2
Total shipment-miles^b					
100% truck	145.1	121.4	186.7	96.4	176.8
100% rail	25.5	21.7	33.3	17.7	31.1
Number of interchanges ^c	3	2-4	2-4	2-4	1-2
Cost^d					
100% truck	1,305	1,127	1,615	936	1,538
100% rail	1,207	1,122	1,376	982	1,345

^aNumber of fatalities during the preclosure period.^bOne-way million miles.^cWithin the transportation study area.^dMillions of 1985 dollars.

Table 7-17. Factors used to evaluate disruption of the environment
and cost of infrastructure

	<u>Davis Canyon</u>	<u>Deaf Smith</u>	<u>Hanford</u>	<u>Richton</u>	<u>Yucca Mountain</u>
Parameter	Truck/Rail	Truck/Rail	Truck/Rail	Truck/Rail	Truck/Rail
Access route					
Miles	25/38-54	1/25-35	<3/<3	4/26	16/100
Cost ^a	79/141-269	1/21-44	<6 ^b	3/16	12/151
Upgrade					
Miles	64-68/0	4/0-13	0/0	23/0	0/0
Cost ^a	15-35/0	1/<10	0/0	6/0	0/0
Distance from end of access route to major highway or mainline rail	64-173/30-36	14/0-13	0/48	22/0	0/0
Need for tunnels	Yes	No	No	No	No
Need for bridges	Yes	Yes	No	Yes	Yes
Need for Federal condemnation	Yes	Yes	No	Yes	No
Terrain	Very rugged	Generally flat	Generally flat	Gently rolling	Gently sloping

^aIn millions of 1985 dollars.

^bTotal cost for truck and rail transportation.

Since the Hanford site is the most distant from the large majority of spent-fuel sources, it has the highest relative risk from a national perspective. The introduction of a second repository reduces the effect of distance on the overall transport risk (for a more complete discussion of the effect of a second repository see Appendix A, Section A.11). Transportation safety near the site is considered to be relatively high because of the flat terrain and the good existing transportation network. The population density in the area is moderate.

The Richton site is favorable for the transportation-safety consideration because it is closer to the sources of spent fuel than the other sites. National transportation risks are therefore reduced, and the relative level of transportation safety is high. The site would be more favorable if there were fewer local towns and cities were nearby; however, with the construction and upgrading of the local access routes, local safety should be high as well.

Yucca Mountain is easily accessible, but it is far from most sources of spent fuel. The local rail network that will be developed will effectively bypass Las Vegas. Local roads provide good access to the interstate highway system. One potentially hazardous feature of the access routes is their proximity to an Air Force bombing range. Although this is not expected to present a significant risk, some additional safeguarding of shipments may be required. The local terrain presents no hazards.

Environmental disruption. The second major consideration accounts for the environmental impacts caused by improving the existing infrastructure and constructing new access routes to the site. Though not as important as the first consideration, the potential for environmental disruption has much significance. For example, transportation operations and the development of access routes might adversely affect sensitive species on a large scale (over many miles), and the aesthetic quality of the region may be reduced by the construction of road and rail routes. This consideration reflects the focus in the guideline on local conditions around the site. Effects on the environment along national highways and railroads were considered when those networks were developed for regular commercial traffic. In this respect, the incremental environmental impacts of transporting radioactive waste are not considered to be significant on a national scale.

A contributing factor for this consideration is whether a site requires access routes that would disrupt the environment. Table 7-17 lists the major factors that are considered in evaluating the potential for environmental disruption. A more favorable site would be one that does not require the construction of lengthy access roads. Other qualities that would make a site better are access routes that do not conflict with current land-use plans; no requirements for cuts, fills, tunnels, or bridges; and disruptions that would affect the least number of people. A less favorable site would require significant construction of access routes through pristine or unique environmental areas. Other qualities that reduce the favorability of a site are access routes that conflict with current land-use plans; a requirement for many cuts, fills, tunnels, and bridges; and the displacement of many people by the access route. A summary of the evaluation for each site follows.

Major construction of highways and railroads would be required to reach the Davis Canyon site. This new construction would disrupt previously

undisturbed land and diminish the aesthetic quality of the area. The construction of access routes would require major cuts and fills as well as tunnels. The existing transportation network would also have to be improved.

Deaf Smith County is located on generally flat terrain that would not require major excavation during construction. Upgrading of the existing road is not expected to cause significant environmental impacts. A long segment of new track must be laid to reach the site, but the environmental disruptions would be minor.

For the Hanford site, the truck and rail access routes would be short, and little environmental disruption would result from constructing the access routes. No improvement in the existing transportation network is needed.

The Richton site is on generally flat terrain. Although a long railspur would have to be built to reach the site, it would follow an abandoned railroad right-of-way. The existing local road would have to be upgraded for a significant length. A short length of new road would have to be built to reach the site. The environmental impacts of new construction are not expected to be significant.

To reach the Yucca Mountain site, a long railspur and a moderate length of new road would have to be constructed. A long bridge would also be necessary. The terrain is such that the construction of these routes will cause minimal environmental disruption.

Cost of transportation infrastructure. This major consideration addresses the cost of constructing and upgrading the access routes to the sites. Its importance is gained from the emphasis in the qualifying condition on the local infrastructure and access routes. It is not as important as the first consideration because the protection of health and safety is more important than reducing costs.

The cost of the transportation infrastructure is considered separately from the costs of transporting waste to the site. Table 7-17 presents a comparison of costs for the construction of new road and rail access routes and the upgrading of existing networks at each site.

A favorable site for this consideration is one that needs little, if any, repair or upgrading of access routes. Other qualities of a favorable site include no requirement for Federal condemnation for rights-of-ways, a flat terrain, low costs for rights-of-way, and absence of other local anomalous features that may increase costs. A less favorable site has a poorly maintained or no transportation infrastructure; if it does exist, it is a long distance from the site, thus requiring much new construction. Other qualities of a less favorable site are a mountainous terrain, high costs for rights-of-way, the need to secure rights-of-way by Federal condemnation, and other features that could require expensive mitigation.

Cost of transportation hardware and operations. The least important consideration is the cost of developing the cask fleet and shipping the waste to the repository. This consideration is not as important as the others because transportation costs are relatively insensitive to location, and the protection of health and safety is more important than reducing costs.

The cost of transporting spent fuel to the repository sites depends to some extent on distance; that is, it costs about as much to ship waste 1,000 miles as it does 500 miles. Other factors that can influence cost, at least as determined at this stage of investigation, provide little additional guidance for discriminating among sites. A summary of transportation costs is presented in Table 7-16.

Like transportation safety, transportation cost is also affected by decisions about the configuration of the waste-management system, such as the second repository. The effect of the second repository is considered as quantitatively as possible.

A favorable site is one that is close to the sources of waste, is not subject to weather that will interfere with access to the repository, is served by existing carriers, is located in an area with emergency-response capabilities, is not located near communities that impose legal impediments to transport, and is served by rail routes that require few crew changes. A less-favorable site has characteristics that are the converse of the above factors.

Summary of comparative evaluations

The Richton site is the leading site for the major considerations that address transportation safety and the cost of transportation hardware and operations; it is the second most favorable site with respect to environmental disruption and the cost of the infrastructure. Because of the paramount importance assigned to transportation safety, the Richton site is the most favorable. The Deaf Smith site is distinguished from Richton mainly by being farther from the sources of the waste. The Hanford site is less favorable from a nationwide transportation perspective because it is the farthest from the sources of the waste. Local conditions at Hanford, however, are highly favorable in terms of safety, cost, and environmental disruption. Yucca Mountain, which is about equal in favorability to Hanford, is far from the sources of waste and would require major construction of access routes. Davis Canyon is the least favorable site for this guideline. Although it is moderately far from the sources of the waste, it is not readily accessible because the terrain in the area is very rugged. Moreover, major construction of highways and railroads is required, and it would cause significant environmental impacts.

7.3.2.2 System guideline on environment, socioeconomics, and transportation

Ranked second in importance in the preclosure system guidelines is environment, socioeconomics, and transportation. The pertinent system elements for environment, socioeconomics, and transportation (10 CFR 960.5-1(a)(2)) will, in general, consist of (1) the people who may be affected, including their lifestyles, sources of income, social and aesthetic values, and community services; (2) the air, land, water, plants, animals, and cultural resources in the areas potentially affected by such activities; (3) the transportation infrastructure; and (4) the potential mitigating measures that can be used to achieve compliance with this guideline. To provide a comparative context for understanding the evaluation of this system guideline

in Chapter 6, this section presents a brief summary of the evaluation of each site in terms of the system elements.

At Davis Canyon, the level of suspended particulates and gaseous emissions will increase during repository construction and operation. However, the concentrations of total suspended particulates (TSP) and nitrogen dioxide during all phases would be below the national ambient air quality standards (40 CFR Part 50). Construction lighting may have an effect on skyglow in the vicinity of the site. Repository construction and operation would increase the levels of noise, which may be heard in the Canyonlands National Park. It is expected that direct impacts on cultural resources during siting and construction can be minimized. Indirect impacts would not result in a loss of significant amounts of cultural information.

The site would not intrude on nearby dedicated lands. Transportation access to the Newspaper Rock State Historical Monument and the Canyonlands National Park would be temporarily disrupted. No unique aquatic or terrestrial habitat is likely to be significantly affected by the repository. The overall visual impacts of the repository would not be significant away from the immediate vicinity of the repository, except along Utah 211 and from the Davis Canyon Jeep Trail. The surface facilities would not be visible from any scenic view points or key observation points in Canyonlands National Park. A repository in Davis Canyon would, however, cause a significant adverse visual impact as viewed from the upper reaches of Davis Canyon in the park. Each of the four alternative rail corridors would create significant visual-contrast impacts from two to three key observation points in the area; none of these is inside the park.

Cumulative impacts on the Canyonlands National Park include shared traffic on Utah 211 (during site characterization), increased particulates and noise at the edge of the park, visibility of the site from Davis Canyon at the park boundary, sky brightness at night, and the potential of nearby industrial development. The impact of episodic noise intrusion on solitude in the park would be significant, but of short duration. During repository operations, all impacts mentioned above will be eliminated or reduced in the sections of the park designated for scenic, cultural, or solitude enjoyment purposes.

At Davis Canyon, available labor supplies within commuting distance of the site are expected to be insufficient to meet the requirements of the repository. The projected number of persons (workers and families) expected to in-migrate into the area during peak employment is significant. This would result in significant population increases in the rural communities of Monticello, Blanding, and Moab.

The population increase would require additional community services and facilities. The need for expanded community services and facilities could result in financial burdens to host communities because increased revenues from project and worker expenditures may not immediately be available to finance these capital expenditures. The increased demand for labor could reduce local unemployment but also cause competition and decreases in the labor available for other sectors of the economy. Advance community-development planning and financial and technical assistance can lessen the impacts on affected communities. Increased tax revenues and business activity would contribute to mitigation in the long term. Significant population

increases would also cause social changes within communities. Planning for additional protective, social, and cultural services can mitigate these changes.

Some temporary disruption in the existing vehicle-traffic flow can be expected, and some localized inconveniences experienced, during the construction of new transportation corridors and the upgrading of others. Depending on the alternative road and railroad routes selected for the repository and the time of year, some threatened and endangered species or their preferred habitats may be affected. The radiological risks of transportation appear to be small. Estimates indicate that the maximally exposed individual could receive up to 3 percent of the doses delivered by natural background radiation. It may be possible to provide new highway and rail routes that will not disrupt local cities and towns.

At the Deaf Smith site, the local areas would sustain increases in suspended particulates and nitrogen oxide emissions, particularly during site clearing and construction. Mitigation measures would limit any significant increases of suspended particulates to the immediate vicinity of the site. Preliminary modeling results indicate air quality can be maintained within regulatory standards. Short-term increases in sound levels will occur in areas around drilling sites and near truck-mounted generators during the site characterization. At the nearest residences, noise during some stages of construction could exceed EPA guidelines. Practical engineering measures can be used to prevent runoff and ground-water contamination from the salt pile at the site. Salt-handling and control measures would be used to minimize the deposition of wind-blown salt on adjacent lands.

The site is in an agricultural area that is heavily dependent on irrigation. While the repository would represent a water demand on a limited resource, the demand is less than that required to irrigate an equivalent area. Repository development will divert 5,760 acres from potential agricultural uses. The withdrawal of this land represents less than 1 percent of the total prime farmland in the county. Neither the site nor potential transportation corridors would intrude on any dedicated resource areas. No unique aquatic or terrestrial species are likely to be affected. Structures and equipment at the site during siting and construction would be visible but not visually atypical of the region. Depending on the distance, the visual intrusion will range from moderate to high.

At the Deaf Smith site, employment predictions indicate that the available labor supply within commuting distance to the site would not be sufficient to satisfy repository labor requirements, particularly during the peak employment periods. Some in-migration of workers is therefore likely. The area seems able to absorb the projected population changes without significant disruptions in housing and other community services. However, some increases in the demand for community services can be expected. Increased tax revenues and mitigation grants from the DOE will assist in providing required additional services.

There are several feasible highway and railroad access routes to the Deaf Smith site that do not irreconcilably conflict with Federally protected resource areas. These routes can be designed and constructed with available technology and will not require waste-transportation packaging standards more

stringent than existing NRC and DOT regulations, nor the development of new transportation tasks. A preliminary evaluation of operations over representative highways and railroads to the Deaf Smith site indicates that waste-transportation operations can be conducted over these routes without unacceptable risk to the public or impacts on the environment. Also, adequate protection for the public and the environment can be provided during both the construction of the access routes and during operation over those routes.

For the Hanford site, no adverse environmental impacts have been identified that cannot be mitigated. The site is not within any protected resource areas, and compliance with regulatory requirements should not be a problem. No federally recognized threatened or endangered species are known to use the site as a critical habitat. There are significant native American resources on the Hanford Site, but they are far enough from the repository location so that there would be no significant adverse impacts.

Projected employment and population growth associated with the repository could be readily assimilated by the area. A technically qualified work force (except for miners) is located in the Tri-Cities and surrounding area. Roads, schools, utilities, and housing are all expected to have the ability to accept additional people in the area without stress on community services and facilities.

Access routes to the site would have no undesirable features that would require unique design or construction methods or special features of transportation system components, including the transportation packaging. Risks to public health and safety of proposed access routes would be acceptably low, since these routes are short and pass through areas without population. The environmental impacts of transportation are expected to be acceptably low, since the access routes are short and do not pass through protected resource areas. Projected risks, costs, and other impacts of waste transportation have been considered in repository siting, and transportation operations would be conducted in compliance with applicable regulation.

At the Richton site, the residual air-quality impacts are acceptable because they are below secondary standards. Clearing and construction activities would increase ambient noise levels near the site. Engineering design and distance to the nearest residences in the area will mitigate these noise levels to acceptable levels.

The construction of shafts to the underground facility would require the penetration of aquifers. Engineering safeguards to prevent threats to this water source are a recognized necessity. Existing technology is adequate to provide the needed protection.

Engineering measures can be used to prevent runoff and ground-water contamination from the salt pile at the site. Salt handling and control measures would be used to minimize the deposition of wind-blown salt. No known cultural resources will be affected by project activities.

The site would not intrude on any dedicated land or recreational areas. Any potential transportation rights-of-way that may be required through land under the National Forest System would be sited on existing or abandoned rights-of-way, thus minimizing land disruption.

No unique aquatic or terrestrial species are likely to be significantly affected. The surface facilities will be visible to some areas in the vicinity of the site. However, the emplacement is not likely to affect any existing unique features of the area.

At the Richton site, Employment predictions indicate that the available labor supply within commuting distances to the site will not be sufficient to satisfy repository labor requirements, particularly during peak employment. Some in-migration will therefore occur. Job-training programs can provide opportunities of employment for area residents, thus decreasing in-migration. The area seems capable of absorbing the projected population change without significant disruptions in housing and other community services. However, some increased demand for community services can be expected. Increased tax revenues will be received by State and local government. The town of Richton will experience impacts. This population increase would require expanded community services and facilities and may cause social changes in the town of Richton. Advanced community-development planning can lessen these impacts.

Some temporary disruption in existing vehicular traffic flow can be expected, and some localized inconvenience may be experienced during the construction of new transportation corridors and upgrading of others. The radiological risks of waste transportation appear to be small. Estimates indicate that the maximally exposed individual could receive up to 5 percent of the dose delivered by normal background radiation. Needed new highway and rail routes can be provided without disruption to local cities and towns.

At Yucca Mountain, the potentially significant adverse environmental impacts include (1) the destruction of approximately (1,608 acres) of desert habitat; (2) fugitive-dust emissions from surface preparation, excavation, and manipulation of spoils piles; (3) vehicle emissions from waste transport, personnel transport, and materials transport and the operation of construction equipment; and (4) radioactive-material releases during (a) repository excavation (e.g., from naturally occurring radon), (b) normal repository operation, and (c) accidents. Potential impacts on surface and ground water are considered insignificant, chiefly because there is no perennial surface water in the area, and ground water is several hundred meters beneath the repository horizon. A permanent land withdrawal would be required if the Yucca Mountain site is selected for repository development, and the reservation of water rights is explicit in such an action. Studies to date suggest that aquifers underlying the proposed locations of the surface facilities can produce large quantities of water for long periods without lowering the regional ground-water table. Other potential impacts, such as the diversion of natural runoff and the leaching of materials from excavated rock, are being considered in the repository design, and they are not expected to pose significant environmental problems.

During repository construction, the maximum estimated ambient concentrations of particulates, carbon monoxide, and the oxides of sulfur and nitrogen are not expected to exceed the air-quality limits of 40 CFR Part 50 (1983). Assuming the repository is subject to the "prevention of significant deterioration" provisions of the Clean Air Act Amendments of 1977, the predicted pollutant concentrations would violate none of the applicable standards.

Negative impacts on community services, housing supply and demand, and the finances of State and local government agencies in the affected area are not expected to be significant for repository siting, construction, operations, and decommissioning at Yucca Mountain.

The affected area, including the Las Vegas Valley, has the ability to absorb the repository-related population changes without significant disruptions of community services and without significant impacts on housing supply and demand.

Although community-specific service and housing demands could increase at rates proportional to the maximum 1-year community-population-growth rates estimated with the repository, these rates are generally within the range of those experienced historically by the urban communities and their municipal service providers. Because the unincorporated towns nearest the Yucca Mountain site have limited capability for community services, the potential population growth in these communities would generally impact county-wide service providers. These service providers are more likely to have resources for managing growth. In addition, the community-level growth rates estimated for the unincorporated towns are generally within the range of those experienced historically by Nye and Clark Counties. The work force in southern Nevada is sufficiently large to site, construct, and operate a repository at Yucca Mountain. Although an adequate total work force may be available for a repository at Yucca Mountain, the available work force with mining skills would be inadequate, and the available construction work force may also be inadequate. A repository at Yucca Mountain would increase employment and business sales in southern Nevada. Community services and government revenues are likely to increase.

For rail access to Yucca Mountain, a rail line extending approximately 100 miles from the existing mainline rail facilities at Dike Siding has been proposed. This route would be entirely on lands administered by the DOE and the U.S. Department of the Air Force and public-domain lands under the jurisdiction of the Bureau of Land Management. The terrain over which the rail line would cross is gently sloping. No tunnels and only a minor amount of excavation and fill would be required. A bridge would be required at Fortymile Wash several miles east of Yucca Mountain.

For highway access to the proposed site, a route is projected northward from U.S. Highway 95, originating approximately 0.5 mile west of the intersection of U.S. Highway 95 and Nevada State Route 373. The roadway access would be constructed on federally controlled lands that slope gently and would pose no significant engineering problems. No tunnels and only a minor amount of excavation would be required. Some minor drainage control measures and a bridge spanning Fortymile Wash would be required. The bridge would accommodate both the railroad and trucks. Between Las Vegas and Mercury U.S. Highway 95 is a four-lane divided highway; it is a two-lane highway from Mercury to the access road near the intersection of U.S. Highway 95 and Nevada State Route 373. A requirement for significant upgrading of this regional highway is unlikely.

The evidence does not support a finding that any of the sites is not likely to meet the qualifying condition for environment, socioeconomic, and transportation.

7.3.3 EASE AND COST OF SITING, CONSTRUCTION, OPERATION, AND CLOSURE

7.3.3.1 Technical guidelines

The four technical guidelines in this group address the surface characteristics of the site, the characteristics of the host rock and the surrounding strata, hydrologic conditions, and tectonics. These guidelines are concerned with the ease and cost of siting, constructing, operating, and closing the repository.

7.3.3.1.1 Surface characteristics

The qualifying condition for surface characteristics is as follows:

The site shall be located such that, considering the surface characteristics and conditions of the site and surrounding area, including surface-water systems and the terrain, the requirements specified in §960.5-1(a)(3) can be met during repository siting, construction, operation, and closure.

Major Considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-18), there are two major considerations that influence the favorability of the sites with respect to the qualifying condition. These major considerations, in order of decreasing importance, are (1) the potential for flooding the surface or underground facilities and (2) the characteristics of the terrain.

Evaluation of sites in terms of the major considerations

Potential for flooding surface or underground facilities.

This consideration is derived from the potentially adverse condition. It is important because the effects of flooding can be significant design considerations for cost and safety. The potential for, and the frequency of, flooding depend on the terrain and drainage of a site. Contributing factors are the location and likelihood of flooding from natural causes at the surface or underground facilities, the failure of man made surface-water impoundments, and the failure of engineered components of the repository. A summary of the evaluation for each site follows.

At the Davis Canyon site, a portion of the repository operations area lies within the flood plains of the 100-year and the probable maximum flood. There are no surface-water impoundments whose failure could flood the surface facilities, and there are no known surface characteristics that could cause the failure of engineered repository components. The potential for flooding would be reduced by using fill to elevate the site and constructing a lined flood-control channel.

Parts of the Deaf Smith site lie in the flood plains of the 500-year and the probable maximum flood, but no safety-related facilities would be

Table 7-18. Guideline-condition findings by major consideration—
surface characteristics^{a, b}

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: POTENTIAL FOR FLOODING OF SURFACE OR UNDERGROUND FACILITIES					
Potentially adverse condition					
Surface characteristics that could lead to the flooding of surface or underground facilities by the occupancy and modification of flood plains, the failure of existing or planned man-made surface-water impoundments, or the failure of engineered components of the repository.	P	P	P	P	P
MAJOR CONSIDERATION 2: TERRAIN CHARACTERISTICS					
Favorable condition 1					
Generally flat terrain.	NP	P	P	P	P
Favorable condition 2					
Generally well-drained terrain.	P	P	P	P	P

^a Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

^b Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

threatened by either flood. There are no surface-water impoundments that could flood the surface facility, and surface characteristics should not lead to failures of engineered repository components. Any effects of potential flooding would be mitigated by filling during construction.

The elevation of the Hanford site protects it from the probable maximum flood of the Columbia and Yakima Rivers, including both natural flooding and dam-breached floods. A shallow probable maximum flood could occur in the southwestern portion of the site along the drainage channel of the intermittent Cold Creek. The duration of such a flood would be short, and its effects could be mitigated to preclude any danger to the workers or to the surface and subsurface facilities.

During an estimated probable maximum flood at the Richton site, the head waters of the Fox Branch river could flood the area proposed for surface facilities. There are no existing or planned man-made surface-water impoundments in the vicinity of the Dome. It is assumed that Fox Branch would be diverted and channeled around the surface facilities and that grading and fill operations would raise the elevation of the site area above the flood plain.

At the Yucca Mountain site, the exploratory shaft would be located in a wash within a flood plain that would be affected by sheet and debris flow. Parts of the candidate locations are in an area that would be affected by the 500-year and the regional maximum floods. There are no existing or planned man-made surface-water impoundments near the site that could flood the surface facilities. Some engineering measures would be required to mitigate the impacts of the probable maximum flood. The hazards of sheet and debris flow at the exploratory shafts could be mitigated by measures like channel lining or diversion.

Terrain characteristics. This consideration addresses the effects of the terrain and drainage characteristics of a site on repository construction, operation, and closure. This consideration is derived from the first and second favorable conditions. It is less important than the first consideration because the characteristics of the terrain are more closely related to the ease and cost of construction than to safety and can generally be mitigated more readily than conditions that could cause flooding.

The contributing factors for this major consideration are the terrain and drainage characteristics of the site, the potential for landslides, and soil characteristics. A summary of the evaluation for each site follows.

The area around the Davis Canyon site is characterized by steep canyons and rugged terrain. Though the terrain at the surface facilities is quite flat, the terrain through which the access roads and railroad would be constructed is rugged. Existing drainage would be rechanneled around the surface facilities during construction. Soils are likely to be well drained, with low water retention since their parent materials are mainly sandstones and siltstones.

The surface of the Deaf Smith site is nearly flat, sloping eastward less than 1 percent. Topographic features include small, internally drained lake basins (playas) and narrow stream valleys that carry surface water after

rainstorms. Soils appear to be acceptable for a large grading operation during repository construction.

The Hanford site is surrounded by an area of generally flat terrain for a radius of nearly a mile. The lack of surface-runoff features suggests the relatively coarse surficial sediments are effective in keeping the surface well drained and preventing surface-runoff features from developing north and east of the Cold Creek flood plain.

The Richton site is surrounded by generally flat terrain, with slopes of 3 to 4 percent and locally up to 10 percent. The soils are generally well drained, though small temporary ponds and marshy areas may form in the area immediately after a heavy rainfall. Soils appear to be acceptable for large grading operations during repository construction.

At Yucca Mountain, potential locations for the surface facilities are on the eastern side of the mountain. All are generally flat and covered with alluvium derived from adjacent highlands. The surface slope at these locations is less than 5 percent and in several places less than 3 percent. The exploratory-shaft facilities would be built within a wash that is partly surrounded by rugged terrain. Yucca Mountain has a well-established drainage system because of its porous alluvial soils and eastward-dipping slopes.

Summary of comparative evaluation

The most favorable site is Deaf Smith where only small parts of the site would be affected by the probable maximum flood. At Hanford, which is slightly less favorable, the probable maximum flood may reach portions of the surface facilities. Both the Deaf Smith and the Hanford sites have flat terrain that is generally well drained.

The Richton and the Yucca Mountain sites are somewhat less favorable than Deaf Smith and Hanford. At Richton site, the surface facilities would be located in the flood plain of the probable maximum flood, but the potential for flooding could be reduced by diverting the Fox Branch stream. Ponds may form after a heavy rainfall because the site is on flat terrain that is not well drained. At Yucca Mountain the exploratory-shaft facilities would be in a wash that is subject to sheet-and-debris flow and surrounded by rugged terrain. Parts of the candidate locations for the surface facilities may be within the flood plains of the 500-year and regional maximum floods. Although the surface facilities would be built on flat terrain, the site is well drained.

The Davis Canyon site is the least favorable for this guideline. The surface facilities at Davis Canyon would be within a 100-year flood plain, and the area is surrounded by steep canyons and rugged terrain. More-extensive engineering measures, such as channeling and drainage diversion, would be necessary to mitigate the impacts of a 100-year flood.

7.3.3.1.2 Rock characteristics (preclosure)

The qualifying condition for preclosure rock characteristics is as follows:

The site shall be located such that (1) the thickness and lateral extent and the characteristics and composition of the host rock will be suitable for accommodation of the underground facility; (2) repository construction, operation, and closure will not cause undue hazard to personnel; and (3) the requirements specified in Section 960.5-1(a)(3) can be met.

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-19), there are three major considerations that influence the favorability of sites with respect to the qualifying condition. In order of decreasing importance these considerations, are (1) in situ conditions that could lead to safety hazards or difficulties during repository siting, construction, operation, and closure; (2) in situ conditions that could require engineering measures beyond reasonably available technology in the construction of the shafts and the underground facility, and (3) flexibility in selecting the location and configuration of the underground facility.

Evaluation of sites with respect to major considerations

Safety hazards and difficulties. This consideration includes in situ conditions that could lead to safety hazards or difficulties during repository siting, construction, operation, and closure. It is related to the qualifying condition through concern about safety hazards to workers and the costs and technical feasibility of mitigating difficult conditions and safety hazards. It is derived from the second favorable condition and the third, fourth, and fifth potentially adverse conditions. Because of its concern with the safety of workers, this is the most important of the considerations related to this guideline. A summary of the evaluation for each site follows.

At Davis Canyon, the mechanical properties of the salt are such that no significant safety hazards from rock instability are expected. A significant safety hazard is the potential for the presence of combustible gas. Although there is no direct evidence that such gas is present at the site, experience in salt mines at other locations suggests that it may occur. The hazards from gas can be mitigated by following safety procedures and providing adequate ventilation. The requirements for artificial rock support are expected to be relatively minor (only occasional bolting) because of the apparent massiveness of the salt and the lack of nonsalt interbeds in the host rock. Also, the presence of any carnallite in the salt should not require increased artificial support since no differences in rock strength have been observed between Paradox Basin salt and carnallite during preliminary testing. However, maintenance of underground openings may be required because of salt creep at

Table 7-19. Guideline-condition findings by major consideration--
rock characteristics (preclosure)^{a, b}

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: SAFETY HAZARDS OR DIFFICULTIES DURING REPOSITORY SITING, CONSTRUCTION, OPERATION AND CLOSURE, INCLUDING RETRIEVAL					
Favorable condition 2					
A host rock with characteristics that would require minimal or no artificial support for underground openings to ensure safe repository construction, operation and closure.	NP	NP	NP	NP	P
Potentially adverse condition 3					
Geochemical properties that could necessitate extensive maintenance of the underground openings during repository operation and closure.	P	P	NP	P	NP
Potentially adverse condition 4					
Potential for such phenomena as thermally induced fracturing, the hydration and dehydration of mineral components, or other physical, chemical or radiation-related phenomena that could lead to safety hazards or difficulty in retrieval during repository operation.	P	P	P	P	NP
Potentially adverse condition 5					
Existing faults, shear zones, pressurized brine pockets, dissolution effects, or other stratigraphic or structural features that could compromise the safety of repository personnel because of water inflow or construction problems.	P	P	P	P	NP
MAJOR CONSIDERATION 2: ENGINEERING MEASURES BEYOND REASONABLY AVAILABLE TECHNOLOGY					
Potentially adverse condition 2					
In situ characteristics and conditions that could require engineering measures beyond reasonably available technology in the construction of the shafts and underground facility.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 3: FLEXIBILITY IN LOCATING THE REPOSITORY WITHIN THE HOST ROCK					
Favorable condition 1					
A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration and location of the underground facility.	P	NP	P	P	NP

Table 7-19. Guideline-condition findings by major consideration--
rock characteristics (preclosure)^{a,b} (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 3: FLEXIBILITY IN LOCATING THE REPOSITORY WITHIN THE HOST ROCK (Continued)					
Potentially adverse condition 1					
A host rock that is suitable for repository construction, operation and closure, but is so thin or laterally restricted that little flexibility is available for selecting the depth, configuration, or location of an underground facility.	NP	P	NP	NP	P

^a Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

^b Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

the candidate horizon. Salt creep will gradually reduce the size of underground openings, and, if significant, may require reexcavation to maintain minimum required dimensions. Salt creep could be a major factor if the waste needs to be retrieved, because it could cause difficulties in maintaining room stability and emplacement holes. However, available information indicates that the salt at Davis Canyon should have a relatively low rate of creep during the duration of the preclosure period.

At the Deaf Smith site, possible safety hazards are the potential for mine-roof instabilities, water inflow down the shaft from aquifers above the repository, and the presence of combustible gas. Interbeds in the salt above the underground openings may cause mine-roof instabilities. Rock falls can be prevented by adequate artificial supports. Water inflow from overlying aquifers can readily be prevented through ground-treatment and shaft-sealing techniques. Although there is no direct evidence that combustible gas is present at the site, experience in salt mines at other locations suggests that it may occur. The hazards from such gas can be mitigated by following safety procedures and providing adequate ventilation. The only artificial rock support required at the site is expected to be regular rock bolting, which will be needed to minimize mine-roof instabilities caused by interbeds in the roof. As at Davis Canyon, maintenance of underground openings may be required because of salt creep. Available information indicates that the salt at the Deaf Smith site would creep at a moderate rate during the duration of the preclosure period.

The safety hazards at the Hanford site are the potential for rock instabilities, large water inflows, high temperatures in the underground facility, and the presence of combustible gas. The high-stress conditions and high rock strength of the basalt suggest a possibility for rock bursts or other hazardous rock movements. However, preliminary evaluations indicate that such bursts are not likely to occur because of the closely jointed nature of the dense interiors, low extraction ratios, and the installation of rock-support systems. Regularly spaced rock bolting and shotcrete over wire mesh would probably be used at Hanford to support the underground excavations, but the extent of needed artificial supports is uncertain because of a lack of experience under similar conditions and a lack of understanding of the impact of thermally induced stress in the emplacement rooms. The high underground temperatures are not expected to cause a significant deterioration of support or instability of the rock. The basalt should not creep significantly, but maintenance, which is typical of deep hard-rock excavations, will probably be required. The potential for large water inflows can be reduced by probing with exploratory boreholes and mitigated through ground treatment and other methods. Combustible gas may be present as it comes out of solution from the ground water. Although the expected quantity of gas is uncertain, the hazards from the gas can be mitigated by following safety procedures and providing adequate ventilation. High temperatures (120°F) in the host rock also pose a potential hazard to workers, but this hazard can be mitigated by providing ventilation, protective clothing, and artificial cooling. There is a potential for minor difficulties in waste retrieval if the emplacement holes do not remain stable during the retrieval period.

At the Richton site, the mechanical properties of the salt are such that no significant safety hazards from rock instability are expected. A possible safety hazard is the potential presence of combustible gas. Although there is no direct evidence that gases are present, experience in salt mines at other locations indicates that it may occur. Hazards from gas can be mitigated by following safety procedures and providing adequate ventilation. On the basis of experience with artificial support in salt mines in the Gulf Coast region, the artificial support required at the Richton Dome is expected to be widely spaced rock bolting. As with the other salt sites, significant maintenance of underground openings may be required because of salt creep. However, the magnitude of creep over long time periods is highly uncertain at the Richton Dome, as it is at the other sites. Available information indicates that salt at the Richton Dome would undergo a moderate rate of preclosure creep.

At Yucca Mountain, safety hazards are limited to the potential for rock falls. The rock strength of welded tuff and in situ stresses are favorable. However, the fractured nature of the tuff could cause rock falls in underground openings. Faults encountered in the underground facility may also contribute to local instabilities because of the poor quality of rock associated with brecciated fault zones. The potential for rock falls can be mitigated through the use of appropriate artificial supports for the underground openings. On the basis of previous excavation at the Nevada Test Site, the expected artificial support requirements at Yucca Mountain are regularly spaced rock bolts with steel mesh covering the rock surface. Occasional supplemental bolting or shotcrete may be required in areas of poor-quality rock, but these requirements are minimal compared with the ground support needed in similar underground construction projects. Since the tuff does not creep, little deterioration of the rock and the artificial support is expected because of time and temperature changes. Fractures in the tuff could complicate retrieval, especially if waste is emplaced in long horizontal holes. Such difficulties could be avoided by providing liners for the emplacement holes.

Complexity of engineering measures. This consideration includes in situ characteristics and conditions that could require engineering measures beyond reasonably available technology in the construction of shafts and underground facilities. The complexity of engineering measures relates directly to the concern in the qualifying condition with technical feasibility. This consideration is derived from the second potentially adverse condition. Although the success of repository construction depends on its technical feasibility, the complexity of engineering measures is second in importance to the safety of personnel. A summary of the evaluation for each site follows.

At Davis Canyon, the construction of the shafts and underground facility is not expected to require engineering measures beyond existing technology. Shaft sinking, underground excavation, artificial support, and protection against any preemplacement safety hazards (such as gas or brine pockets) can be accomplished with technology that has been developed in the salt-mining industry.

At the Deaf Smith site, the shafts and underground facility would also be constructed with technology developed in the salt-mining industry. However, because the Ogallala aquifer lies above the repository at this site, stabilizing the ground for shaft sinking and providing effective water seals for the shaft liner would be more difficult. In addition, the presence of interbeds at the repository horizon would require additional artificial support in the underground facility.

Although the technology required to construct the underground facility at the Hanford site is reasonably available, constructing the repository shafts by blind hole drilling is at the limit of available technology. The shaft would be drilled in an environment that involves a difficult combination of depth, rock conditions, ground-water conditions, and stress conditions. Because shaft drilling in equivalent environments has not been attempted, a reliable data base is not available. Potential ground-water inflows, gases, and high rock temperatures can be managed with available technology, but the combination of conditions could require engineering measures that are more extensive than that usually required in underground construction.

At the Richton site, the shafts and the underground facility can also be constructed with technology developed in the salt-mining industry. A number of salt mines have operated in the Gulf Coast region, and the expected conditions (and the technology to handle those conditions) are relatively well known.

At Yucca Mountain, the construction of the shafts and the underground facility would not require engineering measures beyond existing technology. Construction experience at the G-tunnel on the Nevada Test Site and in other excavations in tuff, coupled with the unsaturated-tuff conditions, indicate that construction at Yucca Mountain should require proved engineering techniques.

Flexibility. Flexibility in selecting the depth, configuration, and location of the underground facility is related to the thickness and the lateral extent of the host rock--the concern of the qualifying condition. Derived from the first favorable condition and the first potentially adverse condition, this consideration is judged to be less important than worker safety and technical feasibility. A summary of the evaluation for each site follows.

At Davis Canyon, the host salt bed is expected to offer significant flexibility in locating the repository. Its thickness appears to be several times greater than necessary, and the available host rock appears to extend laterally for many kilometers. It also appears that there are no significant interbeds, impurities, or other stratigraphic or structural features within the salt bed that would limit this flexibility. However, this evaluation is based on a limited database for the site.

At the Deaf Smith site, flexibility is limited by the expected presence of interbeds in the host salt bed. Although the host salt bed is relatively

thick, the interbeds in the salt restrict the vertical flexibility for locating the repository. In contrast, there is extensive lateral flexibility because the host rock appears to extend for many kilometers. This evaluation is based on geologic information obtained from boreholes near the site.

The Hanford site appears to offer restricted vertical but significant horizontal flexibility. The thickness of other basalt flows in the area varies significantly over short distances, and the predictability of the host-rock thickness at Hanford is uncertain because of a limited data base.

The host salt at the Richton site appears to offer significant flexibility. Flexibility is greatest in the vertical direction, with the salt dome extending for thousands of meters, but there is some lateral flexibility as well. Although the shape of the dome is relatively well known from boreholes and geophysical surveys, there is a potential for undetected and unfavorable internal structures in the dome that could limit flexibility.

There appears to be significant vertical flexibility to locate a repository at Yucca Mountain, but lateral flexibility may be limited by minor faults, a shallow overburden, or site anomalies. The lateral extent of homogeneous host rock outside the primary repository area has not been established.

Summary of comparative evaluations

Since Yucca Mountain is the most favorable site for the two most important considerations, it is the most favorable site for the preclosure guideline on rock characteristics. Yucca Mountain is expected to have the fewest safety hazards, and it would require only existing construction technology and minimal artificial support and maintenance. The limited host-rock flexibility does not outweigh the favorability of the other considerations.

Davis Canyon is relatively favorable for all the major considerations, but it is less favorable than Yucca Mountain. Although there is some potential for safety hazards and retrieval difficulties, and some maintenance would be needed, Davis Canyon would require only existing construction technology and offers significant flexibility in locating the underground facility. The salt at Davis Canyon is expected to creep at a slower rate than the salt at the Deaf Smith or the Richton site.

The Deaf Smith site is as favorable or only slightly less favorable than the Davis Canyon site for the major considerations. Because of the presence of interbeds, it may be more difficult to engineer the repository and maintain underground openings and waste-retrieval capability. The favorability of the site is further reduced by the limited flexibility for locating the underground facility and the faster rate of salt creep in comparison with the other salt sites.

The Richton site is generally favorable for all considerations, but it is less favorable than Davis Canyon for host-rock flexibility and less favorable than both of the other salt sites with respect to the potential for

combustible gas. Also, the salt at Richton is expected to creep at a faster rate than the salt at Davis Canyon.

Hanford is generally less favorable than the other sites for the most important considerations (safety hazards and difficulties, engineering measures) and more favorable for the least important considerations. The potential safety hazards and the engineering measures required for construction are the key considerations that make Hanford the least favorable site for this guideline.

7.3.3.1.3 Hydrology

The qualifying condition for the hydrology guideline is as follows:

The site shall be located such that the geohydrologic setting of the site will (1) be compatible with the activities required for repository construction, operation, and closure; (2) not compromise the intended functions of the shaft liners and seals; and (3) permit the requirements specified in 960.5-1(a)(3) to be met.

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-20), there are three major considerations that influence the favorability with respect to the qualifying condition. These major considerations, in order of decreasing importance, are (1) the complexity of required ground-water-control measures, (2) the existence of surface-water systems that could cause flooding of the repository operations area, and (3) the availability of water for repository construction, operation, and closure.

Evaluation of the sites in terms of the major considerations

Complexity of required ground-water-control measures. This consideration includes ground-water conditions that could necessitate extensive and complex ground-water-control measures in shafts and drifts during repository siting, construction, operation, and closure. It relates directly to the qualifying condition by favoring hydrologic conditions that are compatible with repository construction, operation, and closure and will not compromise shaft liners and seals. This major consideration is derived from the first favorable condition and the potentially adverse condition. The complexity of required ground-water-control measures is the most important of the three considerations for hydrology because it has the greatest effect on the ease and cost of repository construction, operation, and closure. A summary of the evaluation for each site follows:

Table 7-20. Guideline-condition findings by major consideration--hydrology^{a, b}

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: COMPLEXITY OF REQUIRED GROUND-WATER CONTROL MEASURES					
Favorable condition 1					
Absence of aquifers between the host rock and the land surface.	NP	NP	NP	NP	P
Potentially adverse condition					
Ground-water conditions that could require complex engineering measures that are beyond reasonably available technology for repository construction, operation and closure.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 2: EXISTENCE OF SURFACE-WATER SYSTEMS THAT COULD POTENTIALLY CAUSE FLOODING OF THE REPOSITORY					
Favorable condition 2					
Absence of surface-water systems that could potentially cause flooding of the repository.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 3: AVAILABILITY OF WATER FOR CONSTRUCTION, OPERATION AND CLOSURE					
Favorable condition 3					
Availability of the water required for repository construction, operation, and closure.	P	P	P	P	P

^a Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

^b Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

At the Davis Canyon site, rock units above the host rock and the host rock are generally of low permeability. Several minor aquifers with limited water-producing potential are present above the host rock. The small amounts of ground water that would be encountered during shaft sinking can be readily handled with standard engineering practice.

At the Deaf Smith site, an aquifer is present between the host rock and the ground surface. The potential for ground-water inflows during the sinking of shafts through the High Plains aquifer, the unconsolidated sediments above the repository, and the water-bearing interbeds in the host salt bed can be controlled with established technology, such as pretreatment by freezing. Little ground water is expected within the repository horizon.

At the Hanford site, a number of aquifers exist between the host rock and the ground surface. During shaft sinking, ground water would be controlled with established practices. After construction, seals associated with the shaft liner would protect the shafts and repository drifts from ground-water inflow. The construction of the repository may result in the penetration of water zones under high hydrostatic head. However, the potential for large, inadvertent water inflows can be reduced by probing with exploratory boreholes in advance of drifting to locate water zones under high hydrostatic head.

At the Richton site, several aquifers are present above the host rock and adjacent to the flanks of the dome. Control of ground water during shaft sinking through the sediments above the dome and caprock would require ground freezing because of potentially high ground-water inflows and the presence of unconsolidated sediments. Little water is expected within the dome.

At the Yucca Mountain site, there are no aquifers between the host rock and the ground surface. Because the repository would be located above the water table, no significant amounts of ground water are likely to be encountered in the shafts or underground workings.

Existence of surface-water systems that could flood the geologic repository operations area. This consideration includes ponds, lakes, streams, and manmade impoundments that could flood the underground workings during repository construction, operation, and closure, endangering the safety of workers and interrupting repository operations. It relates to the implied concern in the qualifying condition with the compatibility of surface-water systems with repository construction, operation, and closure. This consideration is derived from the second favorable condition and is considered second in importance because it is generally easier to manage the potential for surface flooding than underground ground-water inflows: standard engineering measures like dikes and berms can minimize the potential for flooding. A summary of the evaluation for each site follows.

At the Davis Canyon site, the area of the surface facilities could be inundated by the 100-year and the probable maximum flood. To reduce the risk of flooding, the site would be filled in to an elevation above the flood level, and control channels would be constructed to divert any flow around the site.

At the Deaf Smith site, minor flooding occurs within the controlled area, but there are no surface-water systems that could flood the restricted area. Although a small portion of the restricted area may intercept the flood plain of the probable maximum flood, there is considerable flexibility for locating surface facilities and shafts to avoid flooding.

At the Hanford site, the probable maximum flood of the Columbia and Yakima Rivers would not reach the repository operations area. The maximum flood of the ephemeral Upper Cold Creek could reach the area proposed for the surface facilities, but flooding would be shallow and short-lived, and it would not pose a significant hazard to surface or subsurface facilities. The 100-year flood of Cold Creek is not expected to reach the surface facilities.

The surface facilities at the Richton site would be located on high ground that is drained by Fox Branch and a tributary of Linda Creek. The present site of the surface facilities would be modified by filling in low-lying areas, constructing dikes, or diverting streams to prevent flooding of the surface and underground facilities.

At the Yucca Mountain site, each of the candidate locations for surface facilities is above the flood plain of the 100-year flood, but parts of these areas would be affected by the 500-year flood and the regional maximum flood. The proposed exploratory-shaft site in Coyote Wash may be subject to localized flooding and debris flow. However, the impacts of this infrequent, localized flooding can be mitigated by engineering measures like channel lining and drainage diversion.

Availability of water for repository construction, operation, and closure. This consideration relates to the availability of an ample source of ground or surface water for repository construction, operation, and closure. It is related to the concern in the qualifying condition about the compatibility of the geohydrologic setting with the ease and cost of construction and is derived from the third favorable condition. This consideration is third in importance because, although it affects the ease and cost of construction, it has a limited effect on the technical feasibility of construction, operation, and closure. A summary of the evaluation for each site follows.

At the Davis Canyon site, ample water for repository development is not available in the immediate vicinity of the site, but water could be purchased from the San Juan Water Conservancy District. The water supply may be taken from the Colorado River south of Potash, Utah, and piped 22 miles from the river to the repository site along the proposed railroad access route.

The availability of water at the Deaf Smith site may be limited because the High Plains aquifer could become depleted through normal irrigation use within the operating lifetime of the repository. Consequently, the underlying Dockum aquifer will be evaluated during site characterization to determine its suitability as a supplementary water supply.

At the Hanford, Richton, and Yucca Mountain sites, there is ample ground water in the immediate vicinity of the sites for repository construction,

operation, and closure. There is little doubt that this water would be available for a repository at these three sites.

Summary of comparative evaluation

The Yucca Mountain site is the most favorable site for the preclosure hydrology guideline. It is the leading site for the most important consideration: the repository would be located in the unsaturated zone, and no significant amounts of ground water are likely to be encountered in the shafts and drifts. There is also ample water available for construction, operation, and closure from a source within the controlled area. Although there is a potential for flash flooding, standard drainage-control measures would protect against such flooding. Current engineering technology is more than adequate to handle the hydrologic conditions that are likely to be encountered at Yucca Mountain.

Davis Canyon is only slightly less favorable for the most important major consideration because little difficulty is expected in controlling ground water at the site. However, there is a potential for flooding, and water for the repository would have to be piped in from the Colorado River.

At the Richton site, shafts can be sunk with standard technology, but ground freezing would be required to control ground-water inflow; therefore, the Richton site is less favorable than Davis Canyon and Yucca Mountain for the most important major consideration. Ample water is available for repository construction, operation, and closure, but engineering measures would be required to divert surface drainage.

The Deaf Smith and the Hanford sites are least favorable for this guideline. At the Deaf Smith site, ground-water conditions would make shaft sinking more difficult and would require ground freezing. There is also uncertainty about the availability of ample water for the life cycle of the repository. However, there is no potential for flooding within the restricted area. At the Hanford site, there is a potential need for ground-water-control measures that are more complex and costly than those at the other sites. There is minimal potential for flooding the surface or subsurface facilities and an ample supply of water for construction, operation, and closure. However, the potential complexity of the required ground-water-control measures is judged to reduce the overall favorability of the Hanford site in comparison with Davis Canyon and Richton.

7.3.3.1.4 Tectonics (preclosure)

The qualifying condition for preclosure tectonics is as follows:

The site shall be located in a geologic setting in which any projected effects of expected tectonic phenomena or igneous activity on repository construction, operation, or closure will be such that the requirements specified in §960.5-1(a)(3) can be met.

Major considerations

The objective of the preclosure tectonics guideline is to ensure that a site is not likely to be affected by tectonic events of such magnitude that unreasonable or unfeasible engineering design features would be required. On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-21), two major considerations are identified that affect favorability with respect to the qualifying condition: (1) the potential for earthquake ground motion at the site and (2) the potential for faulting at the site. These major considerations are of about equal importance.

Evaluation of sites in terms of the major considerations

It is important to note that the third potentially adverse condition is not present at any of the five sites (see Table 7-19). The historical seismicity in the geologic setting was used as the basis of this evaluation because it is representative of earthquake potential for short periods of time, such as the preclosure period for the repository. Current understanding indicates that a seismic event of larger than historical magnitude is not likely (less than about 1 chance in 100) to occur during the operation and closure of the repository. This interpretation does not consider earthquakes that may be associated with design events or ground-motion estimates (the second favorable condition and the second potentially adverse condition) or evidence of active faults (the first potentially adverse condition). These are considered to be of low probability. However, as discussed below, the evaluation of ground-motion potential (first major consideration) does consider the earthquake potential of tectonic structures and faults, and data developed for the evaluation of the third potentially adverse condition.

The qualifying condition for the preclosure tectonics guideline also requires an assessment of the potential for igneous activity at each of the sites. On the basis of preliminary data, igneous activity is not expected to cause any adverse preclosure impacts at any of the sites, and therefore igneous activity is not discussed further in this section.

Potential for earthquake ground motion at the site. This consideration requires an evaluation of whether strong ground motion at the site could lead to safety hazards or difficulties during repository siting, construction, operation, and closure. It is related directly to the concern in the qualifying condition about the effects of tectonic phenomena and technical feasibility. It is derived from the favorable condition and the second and third potentially adverse conditions. This major consideration is about equal in importance to the expected impact of fault displacement. Although the likelihood of ground motion at a given site is generally higher than the likelihood of faulting, ground motion and faulting can both be significant design considerations.

Contributing factors for this major consideration include the historical earthquake record, evidence of man-induced seismicity, estimates of ground motion from historical and man-induced earthquakes, the correlation of earthquakes with tectonic structures and faults, and evaluations of the effects of ground-motion hazards on design. In addition, the evaluation of

Table 7-21. Guideline-condition findings by major consideration--
tectonics (preclosure)^{a, b}

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: POTENTIAL FOR EARTHQUAKE GROUND MOTION AT THE REPOSITORY SITE					
Favorable condition					
The nature and rates of faulting, if any, within the geologic setting are such that the magnitude and intensity of the associated seismicity are significantly less than those generally allowable for the construction and operation of nuclear facilities.	NP	P	NP	P	NP
Potentially adverse condition 2					
Historical earthquakes or past man-induced seismicity that, if either were to recur, could produce ground motion at the site in excess of reasonable design limits.	NP	NP	NP	NP	NP
Potentially adverse condition 3					
Evidence, based on correlations of earthquakes with tectonic processes and features (e.g., faults) within the geologic setting, that the magnitude of earthquakes at the site during repository construction, operation, and closure may be larger than predicted from historical seismicity.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 2: POTENTIAL FOR FAULT DISPLACEMENT AT THE REPOSITORY SITE					
Potentially adverse condition 1					
Evidence of active faulting within the geologic setting.	P	NP	P	NP	P

ground motion depends on the evaluation of potential surface faulting in the geologic setting. The potential for ground motion generally increases as the potential for faulting near the site increases. However, the ground-motion potential from all seismogenic sources cannot be evaluated individually: it must be considered collectively to accurately evaluate the potential for ground motion and associated uncertainties. A summary of the evaluation for each site follows.

At Davis Canyon, the estimated ground motion is not significantly smaller than that generally allowable for nuclear facilities. These estimates are based on the assumption that the maximum earthquake, which has a magnitude of 6.5, could occur at Shay Graben, the closest (10 miles) significant structure in the geologic setting. Ground-motion estimates associated with these faults are moderate compared with design values for nuclear facilities. Since 1979, microearthquake monitoring has detected no seismicity at the site. However, events with a magnitude of up to about 3.0 have occurred in the Paradox Basin. Although the seismic hazard appears to be low, the record of seismicity is limited. Man-induced seismicity may be occurring at one location in the Paradox Basin, but it is not firmly established. Estimates of ground motion will remain uncertain until the faults near Shay Graben and the Needles area and the potential for man-induced seismicity at the site are fully evaluated.

At the Deaf Smith site, there appear to be no Quaternary faults in the geologic setting, and the known faults are not associated with recorded seismic activity. The site has a very low potential for induced seismicity. Predicted ground motions are significantly smaller than those generally allowable for nuclear facilities. Quaternary faulting (i.e., the Meers fault) outside the geologic setting appears to be present along the Amarillo Uplift. Study of the Meers fault to determine its tectonic characteristics and earthquake potential may influence evaluations of the portion of the Amarillo Uplift in the Texas Panhandle. This may effect estimates of ground motion at the site, although the distance to the uplift is more than 30 miles. On the basis of a qualitative understanding of present conditions, projected ground motions are well below the level that is likely to cause significant damage to underground structures.

At the Hanford site, potential ground motions are not significantly smaller than those generally allowable for nuclear facilities. However, the ground motions associated with possible Quaternary faulting in the vicinity of the Hanford site are within reasonable design limits for nuclear facilities. An earthquake record of over 100 years shows the historical seismicity of the Columbia Plateau to be low to moderate. This is consistent with data from seismic monitoring initiated in 1969. Recurrence rates for moderate earthquakes (of a magnitude greater than 6 to 6.5) appear to exceed 10,000 years. Earthquakes are not currently associated with mapped geologic structures, nor do hypocenters align in a manner suggesting that there could be unmapped buried faults in the Pasco Basin. The impact and the likelihood of potential earthquake swarms at the repository site have not been determined. Although uncertainties exist, it is expected that the effects of subsurface ground motion can be mitigated by existing engineering measures.

At the Richton site, ground motion is expected to be significantly smaller than that generally allowable for nuclear facilities. Studies to date

provide no evidence of active faulting during the Quaternary Period and no association of known faults with recorded seismic events within the geologic setting. The site is in an area of extremely low earthquake frequency, and there is little potential for induced seismicity. The nearest known earthquake epicenter is 45 miles away. On the basis of a qualitative understanding of present conditions, predicted ground motions are well below the level that could cause significant damage to underground structures. Uncertainty in estimates of ground motion is considered to be relatively low, primarily because the site is located in a region with a very low level of historical seismicity. However, there is some uncertainty about the southern extent of the New Madrid fault zone. This would likely result in more long-period motion than shaking from a maximum earthquake in the site's geologic setting.

On the basis of current knowledge, there is large uncertainty in the evaluation of potential ground motion at the Yucca Mountain site. Data on the age of the last movement, the total amount of movement during the Quaternary Period, and the extent of faulting within 1 to 5 kilometers of the site are limited, and the assessment of ground motion is preliminary. It is premature to place much confidence in estimates of ground motion until a more complete assessment can be made of the extent of faulting near the site and of the appropriate assumptions for such parameters as fault length, fault displacement, attenuation relationships, and earthquake potential. The brief historical seismic record at Yucca Mountain shows no earthquakes that have produced damaging ground motions, and current estimates of recurrence intervals for large earthquakes (greater than magnitude 7.0) in the geologic setting exceed about 25,000 years. Although estimates of ground motion for the surface and subsurface facilities are not expected to be significantly smaller than for other nuclear facilities, reasonably available technology is expected to be sufficient to accommodate the seismic design requirements. These requirements would be established during site characterization. This judgment is based on current knowledge of faults near the site. The maximum acceleration from ground motion induced by underground nuclear explosions is less than that from natural earthquakes. The reader is referred to Chapter 6 of the environmental assessment for Yucca Mountain for a description of the approach to be used in establishing the appropriate seismic design requirements.

Expected impact of fault displacement at the repository site. This consideration requires an assessment of fault-displacement potential that could lead to safety hazards or difficulties during repository siting, construction, operation, and closure. It is related directly to the concern in the qualifying condition about technical feasibility and the effects of tectonic phenomena. It is derived from the first potentially adverse condition and is equal in importance to the first major consideration. Although the likelihood of faulting at a site is generally lower than the likelihood of ground motion, the need to design for fault displacement can have a significant effect on the site's favorability. Successful construction experience where fault-displacement conditions exist is an important contributing factor to favorability. Contributing factors for this major consideration are the evidence and location of, and rates of movement on, Quaternary faults in the geologic setting. A summary of the evaluation for each site follows.

In the Paradox Basin, Quaternary faulting is suspected in the vicinity of the Davis Canyon site at both Shay Graben and the Needles fault zone. However, additional data are needed to determine whether these displacements are seismogenic or related to gravitational sliding, salt flow, or salt dissolution. These faults do not trend toward the repository operations area, and there is no known seismicity within the site boundaries. Thus, no impact is expected from fault displacement at the repository site. There is uncertainty associated with this conclusion because of the possibility that mining the repository could induce seismicity at the site.

Since no active surface faulting of Quaternary age has been recognized in the geologic setting of the Deaf Smith site, there is no expected impact from fault displacement. The geologic setting has experienced little or no tectonic activity during the Quaternary Period. The Meers fault, which appears to show evidence of recent activity, is outside the geologic setting.

Quaternary faults have been identified within the geologic setting of the Hanford Site, but they do not intersect the repository location. Active faults are not known to be present at the site. Since the site is away from areas of known or suspected surface faults and there is no significant seismicity within its boundaries, no impacts from fault displacement are expected. There is uncertainty associated with this conclusion because the potential effects of earthquake swarms on underground facilities are unknown.

Studies to date provide no geologic evidence of Quaternary faulting in the geologic setting of the Richton site. Growth faults, which are not generally associated with seismicity, may occur in the Mississippi salt basin. However, because the Mississippi salt basin is not considered to contain areas of active subsidence and is isolated from the area of the Gulf Coast that is associated with growth faults in the Wiggins Anticline, active growth faulting is not expected.

There are uncertainties in the data on the age of last movement and the total movement of faults at and near Yucca Mountain during the Quaternary Period. Since the area has been mapped and studied in sufficient detail, it is unlikely that major fault zones are undetected. New data may indicate 1 centimeter of fault displacement in the eastern Crater Flat area more recently than about 6,000 years ago. Estimated recurrence intervals for large earthquakes (magnitude 7.0 or greater) associated with surface faulting appear to be long (on the order of 25,000 years). Only minor seismicity has been detected near the site. These conditions suggest that the potential for fault displacement at the site is low during the preclosure period; thus, there are no expected impacts from fault displacement. Existing seismic design technology can accommodate small amounts of surface displacement if necessary.

Summary of comparative evaluation

The Richton site is the most favorable for the preclosure tectonics guideline. It is located in a region of extremely low ground motion and seismic hazard. Ground motion at the site is likely to be accommodated by reasonably available technology. No seismogenic faults have been identified in the geologic setting.

The Deaf Smith site is similar to the Richton site for the two major considerations, except for a slightly higher potential for ground-motion impacts from the Amarillo Uplift, which reduces its favorability. No seismogenic faults have been identified in the geologic setting, the ground-motion potential for the region is low, and ground motion at the site is likely to be accommodated with existing technologies. There is some uncertainty in the potential for ground motion, primarily because the impact of earthquakes on the Amarillo Uplift requires additional study.

The Davis Canyon and the Hanford sites are favorable with respect to the potential impacts of fault displacement. However, estimates of ground motion at both sites are uncertain because of Quaternary Period faults in the geologic setting and the potential for earthquake swarms at Hanford and man-induced seismicity at Davis Canyon. Although current estimates of ground motion for both sites are considered moderate, the seismic record qualitatively indicates that the seismic hazard for these regions is low. At Davis Canyon the closest known potential seismogenic fault is about 10 miles from the site, but this fault would not intersect the site.

At Hanford, the closest potential seismogenic faults are 6.2 to 7.4 miles from the site, but they, too, would not intersect the Hanford site.

Yucca Mountain is the least favorable site for both major considerations. A qualitative understanding of faulting near the site supports the conclusion that individual faults have long recurrence intervals (on the order of 25,000 years or more) for large earthquakes (magnitude 7.0 and greater). There are uncertainties with respect to the age of the last movement and the total amount of Quaternary movement on faults within 1 to 5 kilometers the site. Although estimates of ground motion are preliminary, it is expected that available technology could accommodate likely ground motion. Final estimates of ground motion will depend on the outcome of further seismic evaluations and the full assessment of nearby faults.

7.3.3.2 System guideline on the ease and cost of siting, construction operation, and closure

The third preclosure system guideline is ease and cost of siting, construction, operation, and closure. The pertinent elements are (1) the site characteristics that affect siting, construction, operation, and closure; (2) the engineering, materials, and services necessary to conduct these activities; (3) written agreements between the DOE and affected States and affected Indian tribes and the Federal regulations that establish the requirement for these activities; and (4) the repository personnel at the site during siting, construction, operation, or closure. It is third in importance because it does not relate directly to the health, safety, and welfare of the public or the quality to the environment. A summary of the pertinent characteristics of the host rock at each site and estimates of the engineering, materials, services, and personnel costs are presented below for the salt, basalt, and tuff sites.

Total life-cycle cost estimates* for a repository in basalt (the Hanford site), salt (the Davis Canyon, Deaf Smith, and Richton sites), and tuff (the Yucca mountain site) are shown in Table 7-22. These estimates were developed as part of the DOE's annual evaluation of the adequacy of the fee (1 mill per kilowatt-hour) paid into the Nuclear Waste Fund for disposal services and do not represent final cost estimates. More definitive estimates will be completed when more-detailed designs and site-characterization data become available. The salt cost estimate was based on design parameters that are representative of a genenic salt site. Therefore, this estimate does not take into account site-specific differences that exist at each salt site.

Table 7-22 Repository cost estimates
(billions of 1984 dollars)

Site	D&E	Construction	Operation	Decommissioning	Total
Basalt	1.5	2.3	8.3	0.2	12.3
Salt ^a	1.8	1.6	4.9	0.2	8.5
Tuff	1.5	1.1	5.8	0.1	8.5

^aAll salt sites.

The major cost components identified in Table 7-22 are defined below

- Development and evaluation (D&E): Includes costs for all activities, excluding final design and construction, that are conducted before repository operation. These activities include site characterization, conceptual and license-application design, licensing, and technology development.
- Construction: Includes costs for final design and costs for the construction of all surface facilities and a limited number of underground waste-disposal rooms and corridors.
- Operation: Includes costs for the construction of most of the underground rooms and corridors and costs for the operation of the surface and underground facilities.
- Decommissioning: Includes cost for the decontamination and decommissioning of the surface facilities.
- Total: Represents the total life-cycle cost for a geologic repository and includes the sum of all the above cost components.

*U.S. Department of Energy, Analysis of the Total System Life Cycle Cost for the Civilian Radioactive Waste Management Program, DOE/RW-0024, Washington, D.C., April 1985.

The uncertainty that has been assigned to these estimates is based on engineering judgment and is +35 percent of the total cost of the facility. This, coupled with a 10 to 40 percent contingency already built into the estimates, reflects the accuracy of preconceptual design from which the costs were derived. The exact contingency used depends on the complexity of the design of specific repository facilities or processes.

Salt repository

Host-rock depth. The horizons of the host rock at the Davis Canyon, Deaf Smith, and Richton sites are 3,000, 2,700 and 2,100 feet below the surface, respectively. The horizon assumed for the generic salt cost estimate is 3,000 feet below the service. This is a relatively deep horizon when compared with other siting alternatives.

Rock conditions and tunnel stability. At the Davis Canyon and Richton sites, the artificial rock support required is expected to be minor (only occasional rock bolting) because of the apparent massiveness of the salt and the absence of nonsalt interbeds in the host rock. However, significant maintenance may be required for underground openings because of salt creep. Salt creep will gradually reduce the size of the underground openings, and reexcavation of the openings will be required to maintain the minimum opening dimensions.

At the Deaf Smith site, the potential for roof instability is due to the interbeds that would exist above the underground openings. Rock falls can be prevented by adequate artificial support (regular rock bolting). As with the Davis Canyon and the Richton sites, significant maintenance may be required.

The in situ rock temperatures for each of the three sites are as follows: 34-43°C (93-109°F) for Davis Canyon, 27°C (81°F) for Deaf Smith, and 50°C (122°F) for Richton site.

The rock conditions assumed for the salt cost estimate include good tunnel stability, like those of the Davis Canyon and Richton sites, and favorable in situ rock temperatures similar to the Davis Canyon site. Reexcavation is assumed to be necessary to maintain the underground openings at all salt sites and was therefore assumed for the cost estimate. These parameters were selected to be representative of a generic salt site.

Ground-water conditions. At the Davis Canyon site, one minor aquifer is present above the host rock. The small amounts of ground water (28 gallons per minute) that would be encountered during shaft sinking can be readily handled with standard engineering practices. Little water is expected at the repository horizon.

At the Richton site, several regional aquifers are present above the host rock and adjacent to the flanks of the dome. Ground-water control during shaft sinking through the above-dome sediments and caprock would require ground freezing because of potentially high ground-water inflows (1,700 gallons per minute) and unconsolidated sediments above the salt dome. Little water is expected at the repository horizon the dome.

At the Deaf Smith site, there are aquifers between the host rock and the ground surface. The control of water while sinking shafts through these aquifers and water-bearing interbeds within the evaporite section can be accomplished with established technology. Potentially high ground-water inflows (1,400 gallons per minute) and unconsolidated sediments above the repository require pretreatment by freezing to allow shaft sinking through these sediments. Little water is expected within the repository horizon.

The salt cost estimate assumed that only small amounts of water would be encountered during shaft sinking (similar to Davis Canyon) and at the repository horizon (similar to all three salt sites). These conditions were assumed to be representative of a generic salt site.

Gassy conditions. Although there is no direct evidence that toxic gas is present at any of the three salt sites, experience in salt mines at other locations suggests the possibility. The hazards from such gas can be mitigated through safety procedures and adequate ventilation. These gassy conditions have been assumed in the generic salt cost estimate.

Subsurface conditions. Although specific salt sites may have certain subsurface conditions that are less favorable than others, on balance, it was assumed that mining will be conducted in a relatively good environment. This assumption was based on the subsurface conditions discussed above for the generic salt site.

Ventilation requirements. The ventilation requirements for salt can be described as moderate in comparison with basalt and tuff. Ventilation requirements are higher than those for tuff because of the deeper repository horizon and gassy conditions, but not as high as those for basalt.

Waste-package costs. The design for the waste package is determined by subsurface conditions. The salt waste package consists of a thick-walled carbon-steel container and an internal canister assembly. The internal canister assembly segregates fuel rods into compartments for the consolidated spent-fuel design, whereas a spaceframe is used for the unconsolidated spent-fuel design. No external packing is assumed. The waste-packages assumed for the generic salt cost estimate are as follows:

<u>Parameter</u>	<u>Unconsolidated spent fuel</u>	<u>Consolidated spent fuel</u>
PWR/BWR ratio	1/2	12/30
Number of packages	4,600	12,200
Material	Carbon steel	Carbon steel

The total cost for the fabrication of all waste packages for a salt repository is \$0.7 billion. This cost is lower than that for both tuff and basalt because salt repository emplaces significantly fewer waste packages than either tuff or basalt.

Excavation quantities. Given the waste-package requirements, the excavation requirements can be calculated. For the cost estimates used here,

it was assumed that about 22 million tons of salt will be excavated. This includes 4 million tons of salt reexcavated because of creep. The total amount excavated is higher than that assumed for basalt and tuff.

Mining method. The generic salt cost estimate assumed that a mechanized mining technique will be used to develop the underground facilities. Using this technique, mining is faster than mining by the conventional drill-and-blast technique, which is used for harder rocks like tuff and basalt.

Mining rate. The mining rate for salt can be characterized as "fast average." This rating is due to high mining productivity (tons per man-shift), which is the result of the following:

- The relative softness of the rock.
- The stability of the underground openings.
- Small quantities of water underground.
- Low temperatures.

The productivity for salt is 13.3 tons per man-shift. Salt has the highest productivity of all sites considered.

Underground-facility construction ease. The construction of the underground facilities will be easier at a repository located in salt than a repository located in basalt or tuff. This conclusion is based on the information previously presented which discussed the less difficult mining conditions associated with the salt repository.

Staffing levels and labor rates. Given the mining conditions expected at the generic salt site assumed for the cost estimate, staffing levels for the underground development can be estimated. The staffing levels (in full-time equivalents) for the emplacement period are as follows:

Surface	863
Underground	<u>252</u>
Total	1,115

These estimates are low when compared with other siting alternatives and result from the more favorable mining conditions expected at the salt sites.

Salt has the lowest labor rate (\$28.50 per hour) of the sites considered. When combined with the low staffing levels assumed for salt, the labor cost for salt is expected to be low.

Underground facilities costs. Assuming the conditions described above, the total (construction, operation, and decommissioning) cost of the underground facilities for a salt repository is \$2.2 billion. This is 26 percent of the total cost of \$8.5 billion shown in Table 7-22. The remaining \$6.3 billion consists of \$1.8 billion for development and evaluation, \$3.8 billion for surface facilities, and \$0.7 for waste packages. The underground facilities cost for salt (\$2.2 billion) is lower than that for the other sites.

Operation duration and backfilling. The life of a salt repository is 53 years long. It consists of a 27-year emplacement period, a 23-year caretaker

period, and a 3-year backfill period. Because salt has the shortest backfill period of all the sites considered, salt also has the shortest operating life. The short operating phase, coupled with the low labor cost, results in low operating costs for salt.

Operating cost. The operating cost for a repository in salt is \$4.9 billion. This is 58 percent of the total cost of \$8.5 billion and is clearly the largest portion of the total-facility cost. The remaining \$3.6 billion consists of \$1.8 for development and evaluation, \$1.6 billion for construction, and \$0.2 billion for decommissioning.

Most of the operating costs are associated with the operation of the surface facilities. Of the \$4.9 billion operating cost, \$2.9 billion is for the operation of the surface facilities, \$1.3 billion is for underground development, and \$0.7 billion is for the fabrication of the waste packages.

Total facility costs. Table 7-23 presents the total facility costs for a generic salt repository. This table summarizes the costs mentioned in this section and is consistent with the costs shown in Table 7-22.

Table 7-23. Cost estimates for a salt repository
(billions of 1984 dollars)

Cost category	D&E	Construction	Operation	Decommissioning	Total
D&E	1.8	0.0	0.0	0.0	1.8
Surface	--	0.8	2.9	0.1	3.8
Underground	--	0.8	1.3	0.1	2.2
Waste packages	--	0.0	0.7	0.0	0.7
Total	1.8	1.6	4.9	0.2	8.5

The total facility cost for salt is the same as for tuff and lower than that for basalt. This is due mainly to the lower underground costs resulting from favorable subsurface conditions.

Basalt repository

Host-rock depth. The interior of the Cohasset flow has been selected as the preferred candidate horizon for the basalt repository. The horizon is approximately 3,300 feet below the surface. It is the deepest horizon of all sites considered.

Rock conditions and tunnel stability. The basalt at the Hanford site is a physically and chemically stable rock that will be little affected by repository conditions. The rock is fractured. Heat-induced and rock-matrix fracturing are expected but will be minor and will not create a safety hazard.

High stress conditions are associated with basalt. This suggests that artificial support would be required for repository construction, operation, and closure. This artificial support is not considered minimal and will consist of rock bolts and shotcrete over wire mesh. This support is needed to control instabilities in the rock caused by stress. An example of a stress-induced instability is rock bursts. However, rock bursts are expected to be mild because of the low extraction ratio planned for the repository excavation and the closely jointed nature of the dense interiors. Rock bolts will use the high strength of basalt to control rock bursts or other deformations.

Basalt should not creep significantly, and therefore, maintenance of the underground openings will not be excessive.

The rock temperature in the Cohasset flow is high (51°C, or 124°F) and is a potential hazard to the health of the personnel working underground. A ventilation system that provides a continuous, acceptable working environment must be installed at the basalt repository. The effects of temperature are not expected to cause significant deterioration of support or instability of the rock.

Ground-water conditions. Aquifers are present between the Cohasset flow and the land surface. Ground-water inflow into the repository is high and is estimated to be about 100 gallons per minute. A worst-case estimate would be as high as 3,400 gallons per minute, but this is considered unlikely. The potential for these large water inflows can be reduced by drilling exploratory boreholes before excavation to identify any zones of abnormal water production.

During shaft sinking and the construction of the underground facility, ground-water will be controlled by established practices. After construction, seals associated with the shaft liner would protect the shafts and the repository drifts from ground-water inflow.

Because the rock temperature is high, it is expected that the water temperature will also be high. There is also the potential for water to enter the repository under high pressure.

Gassy conditions. Methane gas is not indigenous to basaltic rock. However, methane could occur in the underground openings because it might be introduced with any water inflow. A way to minimize the potential for methane entering the underground facilities is to control the water inflow into the repository. Ventilation will be required to control the concentration of any methane present underground. However, because of the limited amount of gas expected underground, gassy conditions were not assumed for the basalt cost estimate.

Subsurface conditions. Mining will be conducted in a difficult environment because of the conditions discussed above.

Ventilation requirements. The ventilation requirements for basalt are higher than those for salt and tuff because of the difficult subsurface conditions described above.

Waste-package costs. The design for the waste package is determined by subsurface conditions. The basalt waste package consists of a thick-walled carbon steel container and an external packing assembly. An internal spaceframe is included for unconsolidated spent fuel. The external packing consists of a mixture of basalt and bentonite. The waste-package parameters assumed for the cost estimate are as follows:

<u>Parameter</u>	<u>Unconsolidated spent fuel</u>	<u>Consolidated spent fuel</u>
PWR/BWR ratio	4/9	4/9
Number of packages	1,000	38,800
Material	Carbon steel	Carbon steel

The total cost for the fabrication of all basalt waste packages is \$1.1 billion. This cost is high because the basalt repository replaces more waste-packages than any of the other sites.

Excavation quantities. Given the waste-package requirements, the excavation requirements can be calculated. For the cost estimates used here, it was assumed that about 19 million tons of basalt will be excavated. This quantity is higher than that assumed for tuff, but lower than that assumed for salt.

Mining method. The basalt design assumed that the conventional drill-and-blast excavation technique will be used to develop the underground facilities. This technique is particularly suited to the subsurface conditions found at Hanford. For example, this technique is required because basaltic rock is very hard. However, the basalt mining method is slower than mechanized mining.

Mining rate. The mining rate for basalt can be characterized as "slow average." This rating is due to a low mining productivity (tons per man-shift), which is the result of the following:

- The hardness of basaltic rock.
- The depth of the repository horizon.
- The high stress conditions.
- The presence of large quantities of water underground.
- High temperatures.
- High excavation quantities.

The productivity for basalt is 3.1 tons per man-shift. This is the lowest productivity of all sites considered.

Underground facilities construction ease. The construction of the underground facilities will be more difficult for a repository located in basalt than a repository located in tuff or salt. This conclusion is based on the information previously presented which discussed the more difficult mining conditions associated with the deeper, higher temperature, saturated zones of the basalt repository.

Staffing levels and labor rates. Given the mining conditions expected at Hanford, staffing levels for the underground development can be estimated. These estimated staffing levels for the emplacement period are as follows:

Surface	917
Underground	1,051
Total	1,968

As shown above, the difficult mining conditions result in high staffing levels. When combined with a high labor rate (\$31.00 per hour), the high staffing levels lead to high labor costs for basalt.

Underground-facility costs. Assuming the conditions described above, the total (construction, operation, and decommissioning) cost of the underground facilities of a basalt repository is \$6.1 billion. This is just under 50 percent of the total cost of \$12.3 billion shown in Table 7-22. The remaining \$6.2 billion consists of \$1.5 billion for development and evaluation, \$3.6 billion for surface-facilities, and \$1.1 billion for waste-packages. The cost of the underground facilities (\$6.1 billion) is the highest of all sites considered.

Operating duration and backfilling. The basalt repository has a longer operating life than both tuff and salt: 61 years. It consists of a 27-year emplacement period, a 23-year caretaker period, and an 11-year backfill period. This is the longest operating phase of all sites considered because basalt assumed the longest backfill period. The long operating life, coupled with the high staffing levels and high labor rates, leads to high operating costs for basalt.

Operating cost. The operating cost for a basalt repository at the Hanford site is \$8.3 billion. This is 67 percent of the total cost of \$12.3 billion and is clearly the largest portion of the total facility cost. The remaining \$4.0 billion consists of \$1.5 billion for development and evaluation, \$2.3 billion for construction, and \$0.2 billion for decommissioning.

Most of the operating costs are associated with underground development. Of the \$8.3 billion, \$4.3 billion is for underground development, \$2.9 billion is the operation of the surface facilities, and \$1.1 billion is for the waste packages.

Total facility costs. Table 7-24 presents the total-facility costs for the basalt repository. This table summarizes the costs mentioned in this section; the costs are consistent with the costs shown in Table 7-22.

Table 7-24. Cost estimates for a basalt repository
(billions of 1984 dollars)

Cost category	D&E	Construction	Operation	Decommissioning	Total
D&E	1.5	0.0	0.0	0.0	1.5
Surface	---	0.5	2.9	0.2	3.6
Underground	---	1.8	4.3	0.0	6.1
Waste packages	---	0.0	1.1	0.0	1.1
Total	1.5	2.3	8.3	0.2	12.3

The total facility cost for basalt is the highest of all sites considered. This is due primarily to the higher underground costs resulting from the difficult subsurface conditions.

Tuff repository

Host rock depth. The proposed repository horizon is about 1,200 feet deep. This is the most shallow horizon of all sites considered.

Rock conditions and tunnel stability. The welded tuff of the Toppah Spring Member at Yucca Mountain is a physically and chemically stable rock that will be little affected by repository conditions. Currently, the rock is fractured, and any additional thermally induced fracturing will be minor.

The rock strength of welded tuff and the associated in situ stresses are favorable. The fractured nature of the tuff, however, may provide the potential for rock falls in underground openings. Faults encountered in the underground facility may also contribute to local instabilities because of the poor quality of rock associated with the fault zones. The potential for rock falls can be mitigated through the use of appropriate artificial supports for the underground openings. Previous excavation experience at the Nevada Test Site indicates that the expected artificial support requirements at Yucca Mountain are regularly spaced rock bolts, with steel mesh covering the rock surface for safety. Occasional supplemental bolting or shotcrete may be required in local areas of poor-quality rock. These requirements are considered minimal.

Little deterioration of the rock and the artificial support is expected over time and from temperature changes, since the tuff does not creep. Therefore, the rock is expected to remain in a stable condition and will not require extensive maintenance for the underground openings.

The rock temperature is favorable (27°C or 81°F) and is not expected to be a hazard to the health of the personnel working underground. The effects of temperature are not expected to significantly affect the stability of the mined openings.

Ground-water conditions. At the Yucca Mountain site, there are no aquifers between the host rock and the land surface. Because the repository would be located above the water table, no significant amounts of ground water are likely to be encountered in the shafts or the underground workings.

Gassy conditions. No significant accumulations of toxic gases are expected at the repository horizon. Therefore, gassy conditions have not been assumed for the tuff cost estimate.

Subsurface conditions. Mining will be conducted in a relatively good environment, assuming the conditions discussed above.

Ventilation requirements. The ventilation requirements for tuff are lower than those for basalt and salt. This is a result of the relatively good environment expected underground.

Waste-package costs. The design for the waste package is determined by subsurface conditions. The tuff waste package consists of a stainless-steel canister and an internal spaceframe. No external packing is assumed. The waste-package parameters assumed for the cost estimate are as follows.

<u>Parameter</u>	<u>Unconsolidated spent fuel</u>	<u>Consolidated spent fuel</u>
PWR/BWR ratio	3/9	6/18
Number of packages	1,400	23,100
Material	Stainless steel	Stainless steel

The total cost of fabricating all tuff waste packages is \$1.1 billion. This cost is high because of the combined effect of emplacing a large number of waste packages and high material costs. The cost of the tuff waste package is higher than the cost of the salt waste package for this reason. However, the tuff waste package costs the same as the basalt waste package. This happens because, though tuff emplaces a smaller number of packages than basalt, the resulting cost savings are offset by the cost of the stainless-steel container, which is higher than the cost of the carbon-steel container for basalt.

Excavation quantities. Given the waste-package requirements, the excavation requirements can be calculated. For the cost estimates used here, it was estimated that about 17 million tons of tuff will be excavated. This is lower than that assumed for salt and basalt.

Mining method. The tuff design assumed that mechanized mining techniques will be used in conjunction with conventional techniques to develop the underground facilities. This should lead to a mining rate that is faster than that basalt (conventional mining only) but not as fast as that for salt (mechanized mining only).

Mining rate. The mining rate for tuff can be characterized as "fast average." This rating is due to a high mining productivity (tons per man-shift), which is the result of the following:

- Shallow repository horizon.
- The stability of underground openings.
- Lack of water underground.
- Lower temperatures.
- Lower excavation quantities.

The productivity for tuff is 9.1 tons per man-shift. The productivity for basalt is significantly lower because of the more difficult mining conditions that will be encountered. The productivity for salt is higher largely because salt is softer than tuff and therefore can use only totally mechanized mining techniques.

Underground facilities construction ease. The construction of the underground facilities will be easier at a repository located in tuff than a repository located in basalt, but not salt. This conclusion is based on the information previously presented which discussed the mining conditions associated with the tuff repository.

Staffing levels and labor rates. Given the mining conditions expected at the tuff site, staffing levels for the underground development can be estimated. The staffing levels for the emplacement period (in full-time equivalents) are estimated to be as follows:

Surface	846
Underground	372
Total	1,218

The staffing estimates can be characterized as low, but not the lowest of all sites considered. Tuff has the highest labor rate (\$32.00 per hour) of the sites considered. However, when combined with the staffing levels assumed for tuff, the labor cost is expected to be low and fall between the labor cost expected as basalt (high) and salt (low).

Underground facility costs. Assuming the conditions described above, the total (construction, operation, decommissioning) costs of the underground facilities for a tuff repository is \$2.3 billion. This is 27 percent of the total cost of \$8.5 billion shown in Table 7-22. The remaining \$6.2 billion consists of \$1.5 billion for development and evaluation, \$3.6 billion for surface facilities, and \$1.1 for waste packages.

Operation duration and backfilling. The tuff repository will be in operation for 58 years. This consists of a 27-year emplacement period, a 23-caretaker period, and an 8-year backfill period. The 58-year operating phase is 3 years shorter than the basalt operating period and 5 years longer than the salt operating period. This is due to the duration of the backfill period assumed for each host rock. Because of the operating period, tuff has moderate operating costs when compared with salt and basalt.

Operating costs. The operating cost for a repository located at the Yucca Mountain site is \$5.8 billion. This is 68 percent of the total cost of \$8.5 billion and is clearly the largest portion of the total facility cost. The remaining \$2.7 billion consists of \$1.5 billion for development and evaluation, \$1.1 billion for construction, and \$0.1 for decommissioning.

Most of the operating costs are associated with the operation of the surface facilities. Of the \$5.8 billion total operating cost, \$2.8 billion is for the operation of the surface facilities, \$1.9 billion is for underground development, and \$1.1 billion is for the waste packages.

Total facility costs. Table 7-25 presents the total facility costs for a tuff repository. This table summarizes the costs mentioned in this section and is consistent with the costs shown in Table 7-22.

Table 7-25. Cost estimates for a tuff repository
(billions of 1984 dollars)

Cost category	D&E	Construction	Operation	Decommissioning	Total
D & E	1.5	0.0	0.0	0.0	1.5
Surface	---	0.7	2.8	0.1	3.6
Underground	---	0.4	1.9	0.0	2.3
Waste packages	---	0.0	1.1	0.0	1.1
Total	1.5	1.1	5.8	0.1	8.5

The total-facility cost for tuff is the same as that salt and lower than that for basalt. This is due mainly to the lower underground costs that result from favorable subsurface conditions.

GLOSSARY AND LIST OF ACRONYMS AND ABBREVIATIONS

GLOSSARY

ablation	All processes by which snow and ice are lost from a glacier; also, the amount lost.
absorbed radiation	A measure of the amount of ionizing radiation deposited in a given mass of absorbing medium. The unit of absorbed radiation is the rad.
access corridor	Access to controlled roads, railroads, transmission for utilities, or other means.
accessible environment	The atmosphere, the land surface, surface water, oceans, and the portion of the lithosphere that are outside the controlled area.
Act	The Nuclear Waste Policy Act of 1982.
actinides	Chemical elements with atomic numbers beginning at 89 and continuing through 103.
active fault	A fault along which there is recurrent movement, which is usually indicated by small periodic displacements or seismic activity.
active dissolution front	See "dissolution front."
active institutional controls	Controls instituted by government to guard a repository against intrusion and to perform monitoring or maintenance operations.
adit	A nearly horizontal passage from the surface by which a mine is entered.
adsorption	Adherence of ions or molecules that are in solution to the surface of solids with which they are in contact.
aeromagnetic survey	A survey made of the magnetic field of the earth by the use of electronic magnetometers suspended from an aircraft.
affected area	Either the area of socioeconomic impact or the area of environmental impact.
affected Indian Tribe	Any Indian Tribe (1) within whose reservation boundaries a repository for radioactive waste is proposed to be located or (2) whose federally defined possessory or usage rights to other lands outside the reservation boundaries arising out of congressionally ratified treaties may be substantially and adversely affected by the locating of such a facility: <u>provided</u> that the Secretary of the Interior finds, upon the petition of the appropriate governmental officials of the Tribe, that such effects are both substantial and adverse to the Tribe.

affected State	Any State that (1) has been notified by the DOE in accordance with Section 116(a) of the Act as containing a potentially acceptable site; (2) contains a candidate site for site characterization or repository development; or (3) contains a site selected for repository development.
aging	Storage of radioactive materials, especially spent nuclear fuel, to permit the decay of short-lived radionuclides.
air-fall tuff	A tuff deposited showerlike from a volcanic eruption cloud.
albite	A white or colorless triclinic mineral of the feldspar group ($\text{NaAlSi}_3\text{O}_8$). It occurs commonly in igneous and metamorphic rocks.
alkaline	Having a pH greater than 7.
alluvial fan	An outspread, gently sloping mass of alluvium deposited by a stream.
alluvial piedmont	Alluvium that lies at the base of a mountain or a mountain range.
alluvium	A general term for clay, silt, sand, gravel, or similar material that is not compacted and has been deposited in fairly recent geologic time by streams, rivers, or floods.
alpha decay	A radioactive transformation in which an alpha particle is emitted by a nuclide, thus changing one nuclide to another that has a smaller atomic number and weight.
alpha particle	A positively charged particle emitted in the radioactive decay of certain nuclides. Made up of two protons and two neutrons bound together, it is identical to the nucleus of a helium atom. It is the least penetrating of the three common types of radiation--alpha, beta, and gamma.
alunite	A mineral with chemical formula, $\text{KAl}_3(\text{SO}_4)_2(\text{OH})_6$. It usually occurs in white, gray or pink masses in hydrothermally altered feldspathic rocks. See also "feldspathic".
amorphous silica	A form of silica that lacks any ordered internal structure.
amphibole	A mineral group that includes common rock-forming minerals characterized by good prismatic cleavage.
analcite	A mineral with chemical formula: $\text{NaAlSi}_2\text{O}_6 \cdot \text{H}_2\text{O}$. It is an isometric zeolite, commonly found in alkali-rich basalts.
andesite	A dark colored, fine-grained, extrusive igneous rock.

angle of internal friction	The angle between a resultant force and the line perpendicular to the plane of friction.
anhydrite	A white to grayish or reddish mineral of anhydrous calcium sulfate, CaSO_4 .
anoxic	A general term meaning in the absence of oxygen.
anticline	An uparched fold composed of strata that dip outward from a common ridge or axis. The core of an anticline contains stratigraphically older rocks and is convex upward.
apatite	A group of hexagonal minerals consisting of calcium phosphate together with fluorine, chlorine, hydroxyl or carbonate in varying amounts. They occur as accessory minerals in igneous rocks, metamorphic rocks, and ore-deposits.
application	The act of making a finding of compliance or noncompliance with the qualifying or disqualifying conditions specified in the siting guidelines, in accordance with the types of findings specified in Appendix III of the siting guidelines.
APPLICON	A computer-aided total graphics design system that generates contour maps, etc. from data input.
aquiclude	A geologic formation that will not transmit water fast enough to furnish an appreciable supply.
aquifer	A formation, a group of formations, or a part of a formation that contains sufficient saturated permeable material to yield sufficient quantities of water to wells and springs.
aquitard	A confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer; a leaky confining bed. It does not yield water to wells or springs, but may serve as a storage unit for ground water. (See also "aquiclude.")
argillaceous	A term applied to all rocks or substances composed of clay minerals or having a notable portion of clay in their composition; examples are shale and slate.
argillite	A compact rock, derived from either mudstone or shale, that has undergone a somewhat higher degree of induration than is present in mudstone or shale.
arroyo	A term applied in the arid and semiarid southwestern U.S. to a small deep flat-floored channel or gully of an ephemeral or intermittent stream.

artesian	A term describing ground water confined under hydrostatic pressure. The water level in a artesian well stands above the top of the artesian water body it taps. If the water level in an artesian well stands above the land surface, the well is a flowing artesian well.
ash-flow tuff	A tuff deposited by an ash flow or gaseous cloud.
atmospheric dispersion	Atmospheric transport of particulates or gases by airflow within the atmosphere and atmospheric diffusion by random air motions.
atmospheric stability class	An index that indicates the atmosphere's ability to disperse airborne releases.
atomic energy defense activity	Any activity of the Secretary of Energy performed in whole or in part in carrying out any of the following functions: naval reactor development, weapons activities, verification and control technology, defense nuclear materials production, defense nuclear waste and materials by-products management, defense nuclear materials security and safeguards and security investigations, and defense research and development.
austenitic	Characteristic of a solid solution in iron of carbon and sometimes other solutes that occurs as a constituent of steel under certain circumstances.
backfill, backfilling	The placement of materials, originally removed or new, into the excavated areas of a mine, including waste-emplacement holes, drifts, accessways, and shafts.
background radiation	Radiation that is produced by sources such as naturally occurring radioactive minerals in the earth, cosmic rays, and naturally occurring radionuclides in living organisms.
bajada	A broad, gently inclined detrital surface extending from the base of mountain ranges out into an inland basin, formed by the lateral coalescence of a series of alluvial fans, and having an undulating character.
barrier	Any material or structure that prevents or substantially delays the movement of water or radionuclides.
basalt	A dark to medium dark igneous rock usually formed from lava flows and composed chiefly of calcic plagioclase and clinopyroxene in a glassy or fine-grained ground mass.
basalt flow	A solidified body of lava formed from the outpouring of molten basalt from a fissure or vent. (See "intraflow structures.")
base metal	Any of the more common or more chemically active metals (e.g., lead and copper).

basement rock	Undifferentiated rocks that underly the stratified rocks of interest in an area.
basin	A depressed area in the earth's surface with no outlet. Sediments may have accumulated in such areas.
Basin and Range province	Physiographic province in the SW U.S. characterized by a series of tilted fault blocks forming longitudinal, asymmetric ridges or mountains and broad, intervening basins.
bedding	The arrangement of rock in layers of varying thickness and character.
bedrock	Solid rock that underlies all soil, sand, clay, gravel, and loose material on the earth's surface.
benchmarking of computer codes	Code-to-code comparisons in which simulations obtained with DOE codes are compared to those obtained with other available codes of the same kind. The test cases used for benchmarking will use data representative of the actual repository setting. Benchmarking is complete when a reasonable consensus between independent code predictions is achieved.
bentonite	A clay, containing the mineral montmorillonite, that was formed over time by the alteration of volcanic ash and has variable magnesium and iron contents. Bentonite can absorb large quantities of water and expand to several times its normal volume.
berm	As used in this document, a relatively narrow, horizontal man-made shelf, ledge, or bench built along an embankment, situated partway up and breaking the continuity of a slope.
beta particle	A negatively charged particle, physically identical with the electron, that is emitted by certain radionuclides.
biological half-life	The time required for an organism to eliminate half the amount of a radionuclide ingested or inhaled.
biotite	A common rock-forming mineral of the mica group. It is black in hand specimen and brown or green in thin section, and it has perfect basal cleavage.
blind-hole drilling	A technique for sinking shafts. It uses a multiple-cone bit with a diameter larger than 6 feet.
block faulting	A type of vertical faulting in which the crust is divided into structural or fault blocks of different elevations and orientations.

blooie line	A pipe or flexible tube that conducts air or other gas laden with cuttings from the collar of a borehole to a point far enough removed from the drill rig to keep air around the drill dust-free.
boiling-water reactor	A nuclear reactor that uses boiling water to generate electricity.
boomtown	A community that experiences a sudden rapid growth and expansion.
borehole	An excavation, formed by drilling or digging, that is essentially cylindrical and is used for exploratory purposes.
borehole jacking test	A test that measures in situ rock-mass deformation through the application of unidirectional pressures to the opposite sides of a borehole.
borehole log	A record of the characteristics and thickness of the different layers of rock or other material encountered in the excavation of a borehole.
borosilicate glass	A silicate glass containing at least 5 percent boric acid and used to solidify commercial or defense high-level waste.
branch corridor	A corridor that runs at an angle to the main corridors of the repository and that leads to the storage rooms.
brattice	A temporary fabric curtain from directing or restricting underground ventilation flow.
breccia	Rock consisting of sharp fragments cemented together or embedded in a fine-grained matrix.
bridge plug	A downhole tool, composed primarily of slips, plug mandrell, and rubber sealing elements that is run in and set in dense, nonfractured rock in a borehole to isolate a zone. Multiple bridge plugs may be set in a borehole to isolate numerous zones.
brine	Highly saline water containing calcium (Ca), sodium (Na), potassium (K), and chlorine (Cl) and minor amounts of other elements.
brine migration	The movement of brine through interstices in rock.
broadband sound	Sound that encompasses the audible frequencies.
bulkhead	A stone, steel, wood, or concrete wall-like structure designed to resist earth or water pressure.

cage	The car or platform of a mine hoist used to carry men or materials.
calcine	Material heated to a temperature below its melting point to bring about loss of moisture and oxidation.
calcite	A common rock-forming mineral (CaCO_3) that is usually white or gray. It is the chief constituent of limestone and most marble.
caldera	A large basin-shaped volcanic depression, more or less circular.
caliche	Gravel, sand, or desert debris cemented by porous calcium carbonte; also the calcium carbonate itself.
Cambrian	The oldest of the periods of the Paleozoic Era, which lasted from 570 million to 500 million years ago.
candidate site	An area, within a geohydrologic setting, that is recommended by the Secretary of Energy under Section 112 of the Act for site characterization, approved by the President under Section 112 of the Act for characterization, or undergoing site characterization under Section 113 of the Act.
canister	A metal vessel for consolidated spent fuel or solidified high-level waste. Before emplacement in the repository, the canister will be encapsulated in a disposal container.
capable fault	A fault that has exhibited one or more of the following characteristics, as described in the NRC's 10 CFR Part 50: (a) movement at or near the ground surface at least once within the past 35,000 years or movement of a recurring nature within the past 500,000 years, (b) macroseismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault, or (c) a structural relationship to a capable fault according to characteristics a and b such that movement on one could be reasonably expected to be accompanied by movement on the other.
capillary fringe	The zone immediately above the water table in which all or some of the rock pores or fractures are filled with water that is under less than atmospheric pressure and that is continuous with the water below the water table.
caprock	Layers of insoluble mineral deposits that may be derived from the dissolution of a salt dome, "capping" the dome.
carnallite	A white, brownish, or reddish mineral, $\text{KCl} \cdot \text{MgCl}_2 \cdot 6\text{H}_2\text{O}$.

carbonate	A mineral compound characterized by a fundamental anionic structure of CO_3^{+2} . Calcite (CaCO_3) is an example of a carbonate.
casing	(1) A liner in a shaft or borehole to prevent entry of loose rock, gas, or liquid, or to prevent the loss of circulating liquid into porous, cavernous, or fractured ground. (2) The process of inserting casing into a borehole.
cask	See "shipping cask" and "transfer cask."
catchment area	As applied to an aquifer, the recharge area and all areas that contribute to it.
Cenozoic	The latest of the eras into which geologic time, as recorded by the stratified rocks of the earth's crust, is divided; this era is considered to have begun about 65 million years ago.
chronic intake	A continuous inhalation or ingestion exposure lasting for days or years.
cinder cone	A conical hill formed by the accumulation of cinders and other pyroclasts around a volcanic vent.
cladding	A long metal tube used to contain pellets of nuclear fuel; usually made of stainless steel or Zircaloy, an alloy of steel and zirconium.
cladding hulls	The empty metal casings that remain after spent fuel is removed from them for processing.
clastic rock	Any deposit that is composed of fragments of preexisting rocks or of solid products formed during the chemical weathering of such older rocks and has been transported some distance from the place of its origin.
clay	A fine-grained natural material composed mainly of hydrous aluminum silicates. It may be a mixture of clay minerals and small amounts of nonclay materials, or it may be predominantly one clay mineral. The type of clay is determined by the predominant clay mineral (i.e., kaolin, montmorillonite, illite, halloysite, etc.).
clinoptilolite	A relatively common zeolite mineral associated with other zeolites; is also a widespread alteration product of intermediate to acid volcanic glass and occurs as a mineral in sedimentary rocks, especially tuffaceous sandstones. It is a potassium-rich variety of the mineral heulandite and is commonly white.

clinopyroxene	Any of the group of pyroxenes crystallizing in the monoclinic system and sometimes containing considerable calcium with or without aluminum and the alkalies.
closure	Final backfilling of the remaining open operational areas of the underground repository facility and boreholes after the termination of waste emplacement, culminating in the sealing of shafts.
coefficient of friction	An experimental constant dealing with forces when two solid bodies that are in contact slide or tend to slide on each other. The constant depends largely on the roughness of the mating surfaces.
coeval	Originating or existing over the same period of time.
cohesion	Shear strength of a rock not related to interparticle friction.
collapse fracture	Any rock structure resulting from the removal of support and consequent collapse by the force of gravity.
collar	The top or uppermost portion of a shaft. A concrete ring or slab around a shaft used to prevent water inflow and to support the headframe.
colloid	A suspension of finely divided particles in a liquid, gaseous, or solid substance. Suspended particles are not easily filtered out.
colluvium	A general term applied to the accumulation of loose incoherent soil and rock material at the base of a slope.
Columbia Plateau	A region of approximately 200,000 square kilometers (78,000 square miles) occupying a major part of eastern Washington, a portion of northeastern Oregon, and a small part of western Idaho. It is underlain by a flood basalt province consisting of approximately 375,000 cubic kilometers (90,000 cubic miles) of basalt; this is called the Columbia River Basalt Group.
commercial waste	Radioactive waste generated in private industrial and other nongovernment facilities--in particular, the spent fuel discharged from nuclear power reactors and the waste resulting from the reprocessing of spent fuel.
complex	In chemistry, any combination of cations with molecules or anions containing free pairs of electrons. An organic complex is a complex in which the cation is combined with an organic ligand. An inorganic complex is formed when the cation is combined with an inorganic ligand.
compressive strength	The maximum compressive stress that can be applied to a material under given conditions before failure occurs.

conceptual model	A physical description of a system devised to show property variations as based on field and laboratory measurements and best technical judgments.
confined aquifer	An underground water-bearing unit or formation with defined, relatively impermeable upper and lower boundaries. It contains confined ground water whose pressure is usually greater than atmospheric pressure throughout.
confinement	As pertains to radioactivity, the confinement of radioactive material within some specified bounds; confinement differs from containment in that there is no absolute physical barrier.
confining unit	A body of impermeable or distinctly less permeable material stratigraphically adjacent to one or more aquifers.
constitutive model	A mathematical model of a material or a process that expresses its essential quality or nature. A constitutive model is expressed by constitutive equations that mathematically express the relationship between the quantities of interest (e.g., constitutive equations establishing a linear elastic relationship between stress and strain).
contact-handled transuranic waste	Transuranic waste, usually contained in metal drums, whose surface-radiation-dose rate (less than 0.2 rem per hour) is sufficiently low to permit direct handling. Such waste does not usually require shielding other than that provided by its container.
containment	The confinement of radioactive waste within a designated boundary.
container	The metal envelope in the waste package that provides the primary containment function of the waste package and is designed to meet the containment requirements of 10 CFR Part 60.
contamination	The presence of radioactive material on the outside surfaces of a transportation vehicle, a shipping cask, repository equipment, or a waste disposal container.
continuous mining machine	A machine equipped with a rotating cutting head with picklike bits for cutting into rock and for dropping the cuttings into a collection device for loading into cars or conveyors.

controlled area	A surface location, to be marked by suitable monuments, extending horizontally no more than 5 kilometers in any direction from the outer boundary of the underground facility, and the underlying subsurface, which area has been committed to use as a geologic repository and from which incompatible activities would be prohibited before and after permanent closure.
conventional shaft-sinking methods	Methods employing drilling, blasting, and mucking procedures in shaft construction.
cooling (spent fuel)	Storage of fuel elements after discharge from reactors, usually under water, to allow for the decay of short-lived radionuclides and hence the decrease of radioactivity and heat emission to acceptable levels. Synonymous with aging.
core (geologic)	A cylindrical section of rock, usually 5 to 10 centimeters in diameter and up to several meters in length, taken as a sample of the interval penetrated by the drill.
craton	A generally large part of the earth's crust that has attained stability and is relatively immobile.
creep	Slow deformation (alteration of form) that results from long application of a stress.
creep closure	Closure of underground openings, especially openings in salt, by plastic flow of the surrounding rock under lithostatic pressure.
cristobalite	A mineral, SiO_2 , that is a high-temperature form of quartz and tridymite, and occurs as white octahedrons in acidic volcanic rocks.
critical path	Environmental exposure pathway that dominates the transport of material, from the source of emission to human receptors.
criticality	The condition of supporting a nuclear chain reaction. It occurs when the number of neutrons present in one generation cycle equals the number generated in the previous cycle.
cryptocrystalline	A texture of rock consisting of crystals that are too small to be recognized and distinguished under an ordinary microscope.
crystalline	Of or pertaining to the nature of a crystal (i.e., having a regular molecular structure).
crystalline rock	An inexact but convenient term designating igneous or metamorphic rock, as opposed to sedimentary rock.

cultural resources	Any of the various nonrenewable artifacts or other antiquities which have been made or utilized by past human cultures. By extension, sensitive areas, which exhibit past human habitation or activities, as well as any contained features or structures are included.
cumulative impact	Projected impact of a proposed facility in combination with other existing and proposed facilities and actions.
cumulative releases of radionuclides	The total number of curies of radioactivity entering the accessible environment in any 10,000-year period, normalized on the basis of radiotoxicity in accordance with 40 CFR Part 191. The peak cumulative release of radionuclides refers to the 10,000-year period during which any such release attains its maximum predicted value.
curie	A unit of radioactivity defined as the amount of a radioactive material that has an activity of 3.7×10^{10} disintegrations per second.
Darcian flow	Flow of fluids that is described by a numerical formulation of Darcy's law.
dacitic	Characteristic of a fine-grained extrusive rock with the same general composition as andesite but having a less calcic feldspar (dacite).
darcy	A unit of measurement of permeability equivalent to the passage of 1 cubic centimeter of fluid, flowing in 1 second under 1 atmosphere of pressure through a porous medium with a cross-sectional area of 1 square centimeter and a length of 1 centimeter.
dBA	A sound level in decibels measured with the A-weighting network of a sound-level meter. The A-weighting network adjusts the measurement to correspond with the frequency response of the human ear.
debris flow (geologic)	A moving mass of rock fragments, soil, and mud, with more than half the particles being larger than sand size.
decay, radioactive	(1) The process whereby radioactive materials undergo a change from one isotope, element, or state to another, releasing radiation in the process. This action ultimately results in a decrease in the number of radioactive nuclei present in the sample. (2) The spontaneous transformation of one nuclide into a different nuclide or into a different isotope of the same nuclide.
decay chain	The sequence of radioactive disintegrations in succession from one nuclide to another until a stable daughter product is reached.

decibel	A unit of measure, on a logarithmic scale, of the ratio of particular sound pressure to a standard reference pressure squared. The reference pressure is 20 micropascals.
decollement	Detachment structure of strata due to deformation, resulting in independent styles of deformation in the rocks above and below.
decommissioning	The permanent removal from service of surface facilities and components necessary only for preclosure operations, after repository closure, in accordance with regulatory requirements and environmental policies.
decontamination	The removal of unwanted material (especially radioactive material) from the surface of, or from within, another material.
decrepitation	The shattering of a rock mass or rock sample caused by the buildup of excessive pressures in contained fluids as a result of heating, or the action of differential thermal expansion or contraction of its heated grains.
defense waste	Radioactive waste derived from the manufacturing of nuclear weapons and the operation of naval reactors.
density log	A gamma-gamma log used to indicate the varying bulk densities of rocks penetrated in drilling by recording the amount of back-scattering of gamma rays.
denudation	The sum of the processes that result in the wearing away or the progressive lowering of the earth's surface by various natural agents, including weather, erosion, mass wasting, and transportation.
deposition	The laying down of rock-forming material by any natural agent (e.g., the mechanical settling of sediment from suspension in water).
design bases	Information that establishes boundaries for design by specifying the functions to be performed by the structure, system, or component of a facility and the values or ranges of values for controlling parameters.
design-basis event	A credible accident or natural phenomenon (e.g., earthquakes or flood) that is used to establish design bases because its consequences are the most severe of all those postulated for other credible accidents or phenomena.
design life	The period of time for which a structure, system, or component is designed to perform its intended function. The design life of the repository ends when the repository is of no further operational use, waste retrieval is no longer a concern, and closure and decommissioning begin.

detritus	Loose rock or mineral material removed directly by mechanical means or deposited at another site.
deviatoric stress	In the engineering discipline of rock mechanics, the difference between the major principal stress and the minor principal stress.
devitrification	The process by which glassy substances lose their vitreous nature and become crystalline.
diagenesis	All the changes undergone by a sediment after its initial deposition, exclusive of weathering and metamorphism, or the recombination or rearrangement of a mineral into a new mineral. Also known as diagenetic alteration.
diapir	A geologic flow structure, either a dome or an anticline, in which overlying rocks have been ruptured by the flow upward of a plastic core material such as salt.
diapirism	The process by which a diapir is produced.
diastrophism	A general term for all movement of the crust produced by earth forces, including the formation of continents and ocean basins, plateaus and mountains, folds of strata, and faults.
diffusion	A solute-spreading phenomenon important only at low ground-water velocities.
dike (geologic)	A tabular body of igneous rock that cuts across the structure of adjacent rocks or cuts massive rocks.
dip	The angle at which a bed, stratum, vein, or any planar feature of rock is inclined from the horizontal. The dip is measured perpendicular to the strike of the planar feature. (See "strike.")
dip-slip fault	A fault in which the earth's displacement is parallel to the dip of the fault, and there is no horizontal component of movement parallel to the strike.
direct work force	People hired for jobs at the repository.
discharge point (or area)	In ground-water hydraulics, the point (or area) where water comes out of an aquifer onto the surface.
discontinuity (seismologic)	A surface at which seismic-wave velocities abruptly change; a boundary between the seismic layers of the earth.
dispersion	The solute-spreading or dilution phenomena caused by mechanical mixing during ground-water movement and molecular diffusion.

disposal	The emplacement in a repository of high-level radioactive waste, spent nuclear fuel, or other highly radioactive material with no foreseeable intent of recovery, whether or not such emplacement permits the recovery of such waste, and the isolation of such waste from the accessible environment.
disposal system	See "repository system."
disqualifying condition	A condition that, if present at a site, would eliminate that site from further consideration.
disruptive event	Any action that could breach a barrier.
dissolution	A process of chemical weathering by which minerals and rocks are dissolved in water.
dissolution front	An underground zone in which rocks or minerals are being dissolved in a fluid (more specifically, in ground water).
distribution coefficient (K_d)	The ratio of the concentration of a solute sorbed by ion-exchange substances (e.g., earth materials, particularly clays) to the concentration of the solute remaining in solution. A large distribution coefficient implies that the substance is readily sorbed and is redissolved slowly. The concentration of a material in the solid phase (i.e., rock or sediment) (moles per gram) divided by the concentration of material in the aqueous phase (moles per liter).
disturbed zone	That portion of the controlled area, excluding shafts, whose physical or chemical properties are predicted to change as a result of underground facility construction or heat generated by the emplaced radioactive waste such that the resultant change of properties could have a significant effect on the performance of a geologic repository.
dolomite	A sedimentary rock consisting mostly of the mineral magnesium calcium carbonate, $\text{CaMg}(\text{CO}_3)_2$. It is commonly found with, and is usually formed from, limestone.
dome (general)	A dome-shaped landform or rock mass; a large igneous intrusion whose surface is convex upward with sides sloping away at low but gradually increasing angles; an uplift or an anticlinal structure, either circular or elliptical, in which the rock dips gently away in all directions.
dome (salt)	A diapiric or piercement structure with a central plug that has risen through the enclosing sediments from a deep mother bed of salt.

dose commitment	The integrated dose that results from an intake of radioactive material when the dose is evaluated from the beginning of the intake to a later time; also used for the long-term integrated dose to which people are considered committed because radioactive material has been released to the environment.
dose equivalent (radiation)	A concept used to describe the effectiveness of a given unit of absorbed radiation dose. The unit of dose equivalent is the rem.
dose limit	The limit established by the Environmental Protection Agency or the Nuclear Regulatory Commission for the exposure of people to radiation.
dose rate	The radiation dose received per unit of time.
dosimetry	The measurement and evaluation of absorbed radiation dose or dose equivalent.
downfaulted	Rocks on the downthrown side of a fault.
downgradient	Movement of ground water from an area of higher hydraulic pressure to one of lower pressure.
downwarping	Subsidence of the earth's crust.
drag fold	A minor fold, usually one of a series, formed in an incompetent bed lying between more-competent beds, produced by movement of the competent beds in opposite directions relative to one another.
drift	In mining, a horizontal opening excavated underground. In geology, a general term for all rock material transported either by a glacier or by proglacial meltwater.
drill-and-blast mining	A method of mining in which small-diameter holes (less than 1 foot) are drilled into the rock and then loaded with explosives. The blast from the explosives breaks the rock from the face of a structure so that rock can be removed. The underground opening is expanded by repeated drilling and blasting.
drill and test	Hydrologic testing of selected rock intervals when each interval is first penetrated by a borehole. This testing takes place before a borehole is completed to its total depth.
drill hole	A cylindrical hole made by drilling, especially one made by cable tool rigs or one made to explore for valuable minerals or to obtain geologic information. Synonymous with borehole.

drill-stem test	A test of the productive capacity of a well when it is still full of drilling mud.
ductility	A property of a solid material that undergoes more or less plastic deformation before it ruptures.
earthquake	A sudden motion or trembling in the earth caused by the release of slowly accumulated strain.
ecosystem	An ecologic system composed of organisms and their environment.
ecotone	An ecological community of mixed vegetation formed by the overlapping of adjoining ecologic communities.
effective porosity	The amount of interconnected pore space and fracture openings available for the transmission of fluids, expressed as the ratio of the volume of interconnected pores and openings to the volume of rock.
Eh	The oxidation potential of a solution.
elastic modulus (modulus of elasticity)	A constant expressing the ratio of the unit stress or strain to the unit deformation of a material when a stress or strain is exerted on the material.
electrical resistivity	The electrical resistance per unit length of a unit cross-sectional area of a material.
emplacement	The act of emplacing radioactive waste, encapsulated in disposal containers, into a prepared hole.
employment multiplier	A figure based on the estimated ratio of the sum of indirect and direct project employment to direct project employment. It is multiplied by the expected project employment to give total direct and indirect employment.
endangered species	Any plant or animal species protected under Public Law 93-205 that is in danger of extinction throughout all or a significant portion of its range (other than species of insects determined to be pests).
engineered- barrier system	The manmade components of a disposal system designed to prevent the release of radionuclides from the underground facility or into the geohydrologic setting. It includes the radioactive waste form, radioactive-waste containers, material placed over and around such containers, any other components of the waste package, and barriers used to seal penetrations in and into the underground facility.
environmental assessment	The document required by Section 112(b)(1)(E) of the Nuclear Waste Policy Act of 1982.

environmental impact statement	The document required by Section 114 of the Nuclear Waste Policy Act of 1982.
eolian	Pertaining to the wind; especially said of sediment deposition by the wind, of structures like wind-formed ripple marks, or of erosion accomplished by the wind.
ephemeral drainage	A stream or portion of a stream that flows briefly in direct response to precipitation in the immediate vicinity and is dry during some or most of the year. Its channel is at all times above the water table.
epicenter (of an earthquake)	The point on the earth's surface directly above the exact subsurface location of an earthquake.
erg	A unit of energy or work equal to the work done by a force of 1 dyne acting over a distance of 1 centimeter.
erosion	The wearing-away of soil and rock by weathering, mass wasting, and the action of streams, glaciers, waves, wind, and underground water.
escarpment	A long, more or less continuous cliff or relatively steep slope that was produced by erosion or faulting and faces in one general direction, breaking the continuity of the land by separating two level or gently sloping surfaces.
evaluation	The act of carefully examining the characteristics of a site in relation to the requirements of the qualifying or disqualifying conditions specified in the siting guidelines. Evaluation includes the consideration of favorable and potentially adverse conditions.
evaporite	A sedimentary rock composed primarily of minerals from a solution that became concentrated by evaporation, especially salts deposited from a restricted or enclosed body of seawater or from the water of a salt lake.
exclusion area	The area surrounding a nuclear facility in which the licensee has the authority to control all activities, including the exclusion or removal of personnel and property from the area.
expected	Assumed to be probable or certain on the basis of existing evidence and in the absence of significant evidence to the contrary.
expected repository performance	The manner in which the repository is predicted to function, considering those conditions, processes, and events that are likely to prevail or may occur during the time period of interest.

exploratory shafts	Excavations into the host rock to the depth of the repository. The shafts will be large enough to allow people and test equipment to be transported from the surface to the underground excavations.
extensometer	An instrument used to measure strain.
extraction ratio	The ratio of the amount of rock removed to the total amount of rock available in a given area.
extrusive	Igneous rock that has been erupted onto the surface of the earth.
facies	The aspect, appearance, and characteristics of a rock unit, usually reflecting the conditions of its origin, especially as differentiating the rock unit from adjacent or associated units.
fallout (radioactive)	Fission and activation products produced by the above-ground detonation of a nuclear device.
far field	The portion of the geologic setting that lies beyond the near field.
fault	A fracture or zone of fractures along which there has been displacement of the sides relative to one another, parallel to the fracture or zone of fractures.
fault block	A structural unit of the earth's crust that is formed by faulting and is bounded completely or in part by faults. This structure behaves essentially as a unit during tectonic activity.
fault escarpment	See "fault scarp."
fault plane	The plane along which faulting has taken place.
fault scarp	The cliff or escarpment formed by a fault that reaches the earth's surface.
fault system	A system consisting of two or more fault sets that were formed at the same time.
faulting	The process of fracturing or displacement that produces faults.
favorable condition	A condition that, though not necessary to qualify a site, is presumed, if present, to enhance confidence that the qualifying condition of a particular siting guideline can be met.

feldspar	A group of abundant rock-forming minerals of the general formula $MAI(Al, Si)_3O_8$, where M is potassium, sodium, calcium, barium, rubidium, strontium, or iron. Feldspars are the most widespread of any mineral group and constitute 60 percent of the earth's crust.
feldspathic	Containing feldspar as a principal constituent.
ferromagnesian	Containing iron and magnesium.
finding	A conclusion that is reached after evaluation.
finite-element computer code	A computer code that uses the finite-element method. The finite-element method is a method of numerical analysis that divides a region of interest into discrete elements and represents the behavior of the elements with a set of simultaneous equations. Solution of the set of equations yields the behavior at discrete points within the region of interest.
fission (nuclear)	The division of the atomic nuclei into nuclides of lower mass, accompanied by the emission of gamma rays, neutrons, and significant energy.
fission product	A nuclide produced by the fission of a heavier element.
flat-jack test	Testing apparatus used for the determination of in situ stresses or rock-mass deformability.
flooding potential	Areas susceptible to flooding by precipitation-, wind-, or earthquake-induced floods (i.e., floods resulting from dam failure, river blockage or diversion, or distantly or locally generated waves) are considered to have a flooding potential.
flood plain	As defined in 10 CFR Part 60, the lowland and relatively flat areas adjoining inland and coastal waters, including the flood-prone areas of offshore islands and, at a minimum, the area that is subject to a 1-percent or greater chance of flooding in any given year.
fluvial	Of or pertaining to rivers; growing or living in a stream or river; produced by the action of a stream or river.
flux	Rate of flow over a surface (quantity per unit area per unit time).
focal-mechanism solution	A double-couple solution obtained by using the first motion of arrival of P-waves at a particular seismic-recording station.
fold (geologic)	A curve or bend of a planar structure such as rock strata or bedding planes. A fold is usually a product of deformation.

fold belt	An essentially linear region that has been subjected to folding or deformation.
formation (geologic)	The basic rock-stratigraphic unit in the local classification of rocks. It consists of a body of rock generally characterized by some degree of internal lithologic homogeneity or distinctive features.
fracture	A general term for any break or discontinuity in a rock caused by mechanical failure resulting from stress, whether or not it causes displacement on either side large enough to be visible to the unaided eye. It may be a joint, fault, or fissure caused by geological or mechanical process and can range from microscopic to macroscopic and megascopic scales.
fracture permeability	The capacity of a fracture for transmitting a fluid; it is the measure of the relative ease of fluid flow under unequal pressure.
fuel assembly	An assembly of nuclear-fuel rods. Also called "fuel element."
fuel consolidation	The removal of spent-fuel rods from an assembly and repacking in a denser array to reduce the volume per metric ton of fuel.
fuel element	See "fuel assembly."
fuel rod	A long slender, cylindrical tube of stainless steel or Zircaloy containing nuclear fuel in the form of uranium oxide fuel pellets. Also called "fuel pin."
fuel reprocessing	The process whereby spent fuel is dissolved, waste materials are removed, and reusable materials are segregated for reuse.
fugitive emissions	Emissions of any pollutant, including fugitive dust, that do not pass through a stack, chimney, vent, or a functionally equivalent opening and are generated by activities necessary for the continued operation of the source.
fumarole	A vent, usually volcanic, from which gases and vapors are emitted; it is characteristic of a late stage of volcanic activity.
gamma radiation	Electromagnetic ionizing radiation that is emitted during some types of radioactive decay processes. Gamma radiation can penetrate various thicknesses of absorbed material, depending mainly on the energy of the gamma ray and the composition of the material. Gamma radiation is mainly an external radiation hazard.

general siting guidelines	See "siting guidelines."
geochemistry	The study of the distribution and amounts of the chemical elements in minerals, ores, rocks, soils, water, and the atmosphere and the chemical interactions between these phases.
geochronology	The study of time in relationship to the history of the earth.
geodetic survey	A survey of a large land area in which account is taken of the shape and size of the earth and corrections are made for the earth's curvature.
geoengineering	The application of geologic data, principles, and techniques to the study of naturally occurring rock and soil materials or ground water for the purpose of ensuring that geologic factors affecting the location, planning, design, construction, operation, and maintenance of engineering structures and the development of ground-water resources are properly recognized and adequately interpreted, used, and presented for use in engineering practice.
geohydrologic setting	The system of hydrologic units that is located within a given geologic setting.
geohydrologic system	The geohydrologic units within a geologic setting, including any recharge, discharge, interconnections between units, and any natural or man-induced processes or events that could affect ground-water flow within or among those units.
geohydrologic unit	An aquifer, a confining unit, or a combination of aquifers and combining units that constitutes a framework for a reasonably distinct component of a geohydrologic system.
geologic formation	Any igneous, sedimentary, or metamorphic rock represented as a unit in geologic mapping.
geologic repository	A system, requiring licensing by the Nuclear Regulatory Commission, that is intended to be used, or may be used, for the disposal of radioactive waste in excavated geologic media. A geologic repository includes (1) the geologic-repository operations area and (2) the portion of the geologic setting that provides isolation of the radioactive waste and is located within the controlled area.
geologic-repository operations area	A radioactive-waste facility that is part of the geologic repository, including both surface and subsurface areas and facilities where waste-handling activities are conducted.

geologic setting	The geologic, hydrologic, and geochemical systems of the region in which a geologic-repository operations area is or may be located.
geologic system	The host rock or host-rock units and surrounding rocks that provide radionuclide containment and isolation.
geologic time scale	A system of subdividing geologic time, usually presented in the form of a chart showing the names of the various divisions of time, stratigraphy, or rock as currently understood.
geomechanics	The branch of geology that deals with the response of earth materials to deformational forces and embraces the fundamentals of structural geology.
geomorphic processes	Geologic processes that are responsible for the general configuration of the earth's surface, including the development of present landforms and their relationships to underlying structures, and processes that are responsible for the geologic changes recorded by these surface features.
geomorphology	The branch of geology that deals with the general configuration of the earth's surface; specifically, the study of the classification, description, nature, origin, and development of landforms.
geophone	See "seismometer."
geophysical	Pertaining to the properties of the earth related to its structure, composition, and development.
geophysical anomaly	An area or restricted portion of information derived from a geophysical survey that is different in appearance from the general pattern of information.
geophysical log	A graphic record of the measured or computed physical characteristics of the rock section encountered in a well, plotted as a continuous function of depth.
geophysical survey	The use of one or more geophysical techniques, such as earth current, electrical, gravity, magnetic, or seismic surveys, to gather information on subsurface geology.
geosyncline	A large, generally linear trough that deeply subsided over a long period of time and in which a thick sequence of stratified sediments accumulated.
geotechnical	Pertaining to the application of scientific methods and engineering principles to the acquisition, interpretation, and use of knowledge of the materials of the earth's crust.

geothermal gradient	The rate of increase in temperature of the earth with depth. The average geothermal gradient in the earth's crust is approximately 25°C per kilometer of depth.
geotransport	Movement of radionuclides through subsurface soils and rocks, especially the movement of radionuclides in ground water. Used in contrast to "biotransport."
gouge	The clay or clayey material in a fault zone. Also crushed rock along a fault slip.
gneiss	A foliated rock formed by regional metamorphism, in which bands of granular materials alternate with bands of minerals with elongate prismatic habit.
graben	A usually elongated depression of the earth's crust between two parallel faults.
granite	A medium- to coarse-grained intrusive igneous rock consisting primarily of feldspar and quartz.
granite wash	A drillers' term for material eroded from outcrops of granite rock and redeposited to form rock having approximately the same major mineral constituents as the original rock.
grants equal to taxes	Grants made by the Secretary of Energy to each State and unit of general local government in which a site for a repository is approved equal to the amount such State and unit of general local government, respectively, would receive were they authorized to tax site characterization activities at such site, and the development and operation of such repository, as such State and unit of general local government tax and other real property and industrial activities occurring within such State and unit of general local government.
gravity survey	Measurements of the earth's gravitational field at a series of different locations. The purpose is to associate gravitational variations with differences in the distribution or densities of rock and hence rock types.
Great Basin	A subdivision of the Basin and Range province, located in southern Nevada in a broad desert region. The Yucca Mountain site is in the Great Basin.
ground magnetic survey	A determination of the magnetic field at the surface of the earth by means of ground-based instruments.
ground motion	The displacement of the ground due to the passage of elastic waves arising from earthquakes, explosions, seismic shots, and the like.

ground water	Water that occurs beneath the water table in soils and in geologic formations that are fully saturated.
ground-water basin	An underground structure with the character of a basin with respect to the collection, retention, and outflow of water.
ground-water flux	The rate of ground-water flow per unit area of porous or fractured media, measured perpendicular to the direction of flow.
ground-water recharge rate	The rate at which water is absorbed by the ground and later added to the zone of saturation.
ground-water residence time	The time that ground water remains in an aquifer or aquifer system.
ground-water sources	Aquifers that have been or could be economically developed as sources of ground water in the foreseeable future.
ground-water travel time	The time required for a unit volume of ground water to travel between two locations. The travel time is the length of the flow path divided by the velocity, where velocity is the average ground-water flux passing through the cross-sectional area of the geologic medium through which flow occurs, perpendicular to the direction of flow, divided by the effective porosity along the flow path. If discrete segments of the flow path have different hydrologic properties, the total travel time will be the sum of the travel times for each discrete segment.
grout	A mortar or cement-and-water mixture that is used to seal the walls of boreholes and shafts.
guidelines	See "siting guidelines."
Gulf interior region of the Gulf Coastal Plain	A region in northeastern Texas, northern Louisiana, and south-central Mississippi containing several hundred salt domes. Also called the "Gulf Coastal salt-dome basin" or simply the "Gulf interior region." The Richton Dome site is located in this region.
half-life	The time it takes for one-half of the radioactive atoms initially present in a sample to decay. Each radionuclide has a characteristic but constant half-life. (See also "biological half-life.")
hanging wall	The overlying side of a fault or other structure.
halite	Rock salt, which consists of sodium chloride (NaCl).

Hanford Site	A DOE reservation covering nearly 600 square miles in south-central Washington. A portion of this reservation has been identified as a potentially acceptable site in basalt and is called the "Hanford site" or the "reference repository location."
head, hydraulic	See "hydraulic potential" or "hydraulic head."
headframe	The steel or timber frame at the top of a shaft that supports the sheave or pulley for the hoisting cables and serves other purposes.
heat emission	For the purpose of establishing waste-package acceptance criteria, the total amount of heat dissipated from a package of radioactive waste.
heavy metal	All uranium, plutonium, or thorium placed into a nuclear reactor.
high-level radioactive waste	The highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; other highly radioactive material that the Nuclear Regulatory Commission, consistent with existing law, determines by rule to require permanent isolation.
High Plains aquifer	An unconfined aquifer consisting of the Ogallala Formation and the Dockum Group. It is the uppermost of the three major hydrogeologic units beneath the Southern High Plains.
highly populated area	Any incorporated place (recognized by the decennial reports of the U.S. Bureau of the Census) of 2,500 or more persons, or any census-designated place (as defined and delineated by the Bureau) of 2,500 or more persons, unless it can be demonstrated that any such place has a lower population density than the mean value for the continental United States. Counties or county equivalents, whether incorporated or not, are specifically excluded from the definition of "place" as used herein.
historical seismicity	Earthquakes that occurred during recorded history, including those reported before the existence of seismographs (preinstrumental) and those recorded by seismographs (instrumental).
Holocene	An epoch of the Quaternary Period, from the end of the Pleistocene to the present.
Hooke's law	In elastic deformation, the strain is linearly proportional to the applied stress.

horizon	(1) In geology, a given definite position or interval in the stratigraphic column. (2) In this document, a specific underground level or elevation.
host rock	The rock in which the radioactive waste will be emplaced; specifically, the geologic materials that will directly encompass and will be in close proximity to the underground repository.
hot cell	A highly shielded compartment in which highly radioactive material can be handled, generally by remote control.
hundred-year storm	A storm whose intensity is such, on a statistical basis, that it is expected to recur only once every 100 years.
hydraulic conductivity	The rate of water flow through a given cross section of rock in a unit time under a unit hydraulic gradient measured perpendicular to the direction of flow. Synonymous with the ease of ground-water movement.
hydraulic gradient	A change in the static pressure of ground water, expressed in terms of the height of water above a datum per unit of distance in a given direction.
hydraulic head	The height above sea level to which a column of water can be supported by the static pressure at that point. The total hydraulic head is the sum of elevation head, pressure head, and velocity head.
hydraulics	An engineering discipline that deals with the statics and dynamics of fluids.
hydrogeologic unit	Any soil or rock unit or subsurface zone that affects the storage or movement of ground water by its porosity or permeability.
hydrograph	A graph showing stage, flow, velocity, or other characteristics of water with respect to time.
hydrologic modeling	The process of using a mathematical representation of a hydrologic system (as embodied in a computer code) to predict the flow of ground water.
hydrologic process	Any hydrologic phenomenon that exhibits a continuous change in time, whether slow or rapid.
hydrologic properties	The properties of a rock that govern the entrance of water and the capacity to hold, transmit, and deliver water, such as porosity, effective porosity, specific retention, permeability, and the directions of maximum and minimum permeabilities.
hydrologic regime	The distribution, characteristics, and interrelationships of the aqueous components of the geologic environment.

hydrologic transport	Transport of solutes through a geologic medium caused by the movement of ground water.
hydrology	The study of global water and its properties, circulation, and distribution, from the time it falls as rain water until it is returned to the atmosphere through evapotranspiration or flows into the ocean.
hydrostatic pressure	The pressure exerted by the water at any given point in a body of water that is at rest.
hydrostratigraphic unit	A term used for a body of rock having considerable lateral extent and composing a geologic framework for a reasonably distinct hydrologic system.
hydrothermal	An adjective applied to heated or hot solutions, to the processes with which these solutions are associated, and to the rocks, ore deposits, and alteration products produced by these solutions.
hydrothermal alteration	Alteration of rocks or minerals by the reaction of heated water with preexisting solid phases.
hydrothermal reactions	The reaction of materials under aqueous conditions at elevated temperatures and pressures. A component of hydrothermal test mixtures is usually the host rock, but such mixtures may contain any or all waste package components.
hydrovolcanic	Refers to explosive volcanic activity which occurs when magma or magma-generated heat encounters surface waters or ground water.
Hypalon	Brand name for an impermeable synthetic fabric manufactured by DuPont.
hypocenter	The focus or specific point at which initial rupture occurs in an earthquake.
igneous activity	The emplacement (intrusion) of molten rock (magma) into material in the earth's crust or the expulsion (intrusion) of such material onto the earth's surface or into its atmosphere or surface water.
igneous rock	A rock that solidified from molten or partly molten material (i.e., from a magma). Igneous rock is one of the three main classes into which rocks are divided, the others being metamorphic rock and sedimentary rock.
ilmenite	An iron-black opaque rhombohedral mineral with formula, FeTiO_3 . It is a common accessory mineral in basic igneous rocks and is also concentrated in mineral sands.

immobilization	Treatment or emplacement of wastes to impede the movement of their radionuclides.
important to safety	The engineered structures, systems, and components essential to the prevention or mitigation of any accident that could result in a radiation dose to the whole body or an organ of 0.5 rem or more at or beyond the nearest boundary of the controlled area at any time until the completion of permanent closure.
impoundment	The process of forming a lake or pond by a dam, dike, or other barrier; also, the body of water so formed.
indirect employment multiplier	Figure based on the estimated ratio of project employment to the local employment resulting from both the project and project employees with their families purchasing goods and services in the area. It is multiplied by the project employment to give indirect employment growth.
indirect work force	People hired for jobs that are available because of the repository location but not at its facilities; for example, jobs with repository suppliers, town services, or retail business.
induration	The hardening of rock material by heat, pressure, or the introduction of some cementing material.
in-migrants	Workers and their families relocating permanently or temporarily to the vicinity of the site. During construction and operation, these workers and their families are considered to be in-migrants for as long as they are present.
in-migration	Moving into a region or a community, especially as part of a large-scale and continuing movement of population.
in-migration model	The analytical or mathematical representation or quantification of in-migration.
in situ	In its natural or original position. The phrase distinguishes in-place experiments, rock properties, and the like from those conducted or measured in the laboratory.
in situ stress	The magnitude and state of ground stress in a rock mass. The inherent stress in a rock mass at depth.
in situ tests	Tests that are conducted with the subject material in its original place (i.e., at the repository site and depth).
institutional controls	Administrative controls, records, physical constraints, and combinations thereof that would limit intentional or inadvertent human access to the waste emplaced in a repository.

instrumental seismicity	Earthquakes recorded on a seismograph (an instrument designed to detect and record earthquakes).
intensity (earthquake)	A measure of the effects of an earthquake on people, on structures, and on the earth's surface at a particular location; quantified by a numerical value on the modified Mercalli scale.
interbed	A bed of one kind of rock material, typically relatively thin, occurring between or alternating with beds of another kind.
intercalated	Occurring between two rock layers or within a series of layers.
interstice	An opening or space between rock materials or soil particles.
intrusive	Of or pertaining to the emplacement of magma in preexisting rock.
inversion	An atmospheric condition where a lower layer of cool air is trapped below an upper layer of warm air so that the cooler air cannot rise. Since inversions spread air horizontally, contaminating substances cannot be widely dispersed.
ion exchange	A chemical reaction in which mobile ions from a solid are exchanged for ions of like charge in a solution.
ionizing radiation	Any radiation displacing electrons from atoms or molecules, thereby producing ions (e.g., alpha, beta, and gamma radiation).
isolation	Inhibiting the transport of radioactive material so that the amounts and concentrations of this material entering the accessible environment will be kept within prescribed limits.
isolation barrier	The earth material around the underground disposal rooms; it acts to prevent radioactivity from entering the biosphere.
isopach	A line on a map drawn through points of equal thickness of a designated unit.
isopach map	A map that shows the thickness of a geologic unit throughout a geographic area by means of isopach lines at regular intervals.
isopleth	A general term for a line on a map or chart along which all points have a numerically specified constant or equal value of any given variable, element, or quantity with respect to space or time.

isotherm	A line joining data points on a map or chart having the same temperature.
joint	A surface of fracture or parting in rock, without displacement; the surface is often a plane and may occur with parallel joints to form a joint set.
K _d	See "distribution coefficient."
kinematic analysis	The analysis of displacements and strains; it is based on geometric analysis plus a number of assumptions regarding the manner in which geometrical relationships serve to indicate displacements.
L _{dn}	Day-night equivalent sound level: 24-hour equivalent sound level with a 10-dBA penalty applied for the nighttime hours (10 p.m. to 7 a.m.).
L _{ea}	Energy-equivalent sound level: the average of the time-varying sound energy.
lacustrine	Pertaining to, produced by, or inhabiting a lake or lakes.
Lahontan	Pertaining to a Pleistocene lake of the Great Basin. Also a glacial stage correlative to the Wisconsin (see also "Wisconsin").
latite	A porphyritic extrusive rock with nearly equal amounts of plagioclase and potassium feldspar, little or no quartz, and a finely crystalline groundmass.
leachate	A solution obtained by leaching; for example, water that has percolated through soil containing soluble substances and thus contains certain amounts of these substances in solution.
leaching	The dissolution of soluble constituents of a solid material (e.g., the waste to be emplaced in a repository) by the action of percolating water or chemicals.
leakage	Ground-water flow across or through a rock zone of low permeability.
level 1	A specific finding on a disqualifying condition as described in Appendix III of the siting guidelines. A level 1 finding means "the evidence does <u>not</u> support a finding that the site is disqualified."
level 2	A specific finding on a disqualifying condition as described in Appendix III of the siting guidelines. A level 2 finding means "the evidence supports a finding that the site is <u>not</u> disqualified on the basis of that evidence and is <u>not</u> likely to be disqualified."

level 3	A specific finding on a qualifying condition as described in Appendix III of the siting guidelines. A level 3 finding means "the evidence does <u>not</u> support a finding that the site is <u>not</u> likely to meet the qualifying condition."
level 4	A specific finding on a qualifying condition as described in Appendix III of the siting guidelines. A level 4 finding means "the evidence supports a finding that the site meets the qualifying condition and is likely to continue to meet the qualifying condition."
license application	An application for a license from the Nuclear Regulatory Commission to construct a repository.
licensing	The process of obtaining the permits and authorizations required to site, construct, operate, close and decommission a repository.
lignite	A brownish-black coal in which the alteration of vegetable material has proceeded farther than in peat, but not so far as subbituminous coal.
lineament	A linear topographic feature of regional extent that is believed to reflect crustal structure. Examples are fault lines, aligned volcanoes, and straight stream courses.
linear energy transfer	A measure of the energy deposited per unit of path length.
linear expansion	The change in the length of a solid due to a change in temperature. The coefficient of linear expansion is the change in a solid's unit length per 1 degree change in temperature.
lithology	The study of rocks. Also the description of a rock on the basis of such characteristics as structure, color, mineral composition, grain size, and arrangement of its component parts.
lithophysae	Hollow bubblelike structures in rocks; composed of concentric shells of finely crystalline alkali feldspar, quartz, and other materials.
lithosphere	The solid part of the earth, including any ground water contained within it.
lithostatic pressure	The confining pressure at depth in the crust of the earth from the weight of the overlying rocks.
loess	A homogeneous unstratified deposit of windblown dust composed mainly of sand and silt.

log	A record that shows the character of rock being drilled, the drilling process, the drilling tools used, mud weight and condition, personnel on duty, and any pertinent or unusual events occurring during the drilling.
logging	Recording observations, conditions, activities, or measurements.
low-level transuranic waste	See "contact-handled transuranic waste."
low-level waste	Radioactive material that is not high-level radioactive waste, spent nuclear fuel, transuranic waste, or by-product material as defined in Section 11a(2) of the Atomic Energy Act of 1954.
mafic	Said of an igneous rock composed chiefly of dark ferromagnesian minerals.
magma	Naturally occurring mobile rock material, generated within the earth and capable of extrusion and intrusion, from which igneous rocks are thought to have been derived through solidification and related processes.
magnetic survey	A survey made with a magnetometer on the ground or in the air; it reveals local variations in the intensity of the magnetic field.
magnetometer	Instrument that measures the earth's magnetic field or the magnetic field of a particular rock.
magnetite	A black, isometric, strongly magnetic, opaque mineral. it constitutes an important ore of iron and is very common and widely distributed in rocks of all types.
magnetotelluric method	A geophysical surveying method that measures the natural electric and magnetic fields of the earth.
magnitude	The measure of the strength of an earthquake; related to the energy released in the form of seismic waves. Magnitude is quantified by a numerical value on the Richter scale.
man-rem	The unit of population dose. It is obtained by multiplying the average dose equivalent to a given organ or tissue (measured in rem) by the number of persons in a population.

maximally exposed individual	A hypothetical person who is exposed to a release of radioactivity in such a way that he receives the maximum possible individual radiation dose or dose commitment. For instance, if the release is a puff of contaminated air, the maximally exposed individual is a person at the point of the largest ground-level concentration and stays there during the whole time the contaminated-air cloud remains above. This term is not meant to imply that there really is such a person; it is used only to indicate the maximum exposure a person could receive.
maximum credible earthquake	The strongest earthquake that, considering the earthquake history and the tectonic setting of a place, could be reasonably expected to occur during the preclosure and postclosure phases of a repository.
maximum drawdown	The greatest lowering of the water table or potentiometric surface caused by pumping (or artesian flow).
maximum individual dose	The highest radiation dose delivered to the whole body or to an organ that a person can receive from a release of radioactivity. The hypothetical person who receives this dose, the maximally exposed individual, is one whose location, activities, and habits maximize the dose.
maximum permissible concentration	The average concentration of a radionuclide in air or water to which a worker or member of the general population may be continuously exposed without exceeding regulatory limits on external or internal radiation doses.
member of the public	Any individual who is not engaged in operations involving the management, storage, and disposal of radioactive waste. A worker so engaged is a member of the public except when on duty at the geologic-repository operations area.
Mercalli intensity	A scale for measuring earthquake intensity in terms of the effects perceived by people.
mesostasis	The last-formed interstitial material of an igneous rock.
Mesozoic	An era of geologic time, from the end of the Paleozoic to the beginning of the Cenozoic, or from about 225 million to about 65 million years ago.
metamorphic rock	All rocks that were formed in the solid state in response to pronounced changes in temperature, pressure, and chemical environment--changes that take place, in general, below the surface zones of weathering and cementation.

metamorphism (geologic)	The mineralogical, chemical, and structural adjustment of solid rocks to physical and chemical conditions imposed at depth below the surface zones of weathering and cementation, which differ from the conditions under which the rocks originated.
metasedimentary	Sedimentary rocks altered by the effects of heat or pressure or both.
meteorological monitoring station	A tower containing instruments to measure wind speed, wind direction, temperature at different heights, dew point, etc.
mica	A group of minerals consisting of complex silicates with perfect basal cleavage; they split into thin elastic laminae and range from colorless to black.
microearthquake	An earthquake that is not felt or has a magnitude of less than 3 on the Richter scale. Also called "microseism."
millidarcy	A unit of measurement of fluid permeability equivalent to 0.001 darcy.
millirem	1 millirem is 1/1,000 of a rem.
mined geologic disposal system	See "repository system."
mineral	A naturally occurring inorganic element or compound with an orderly internal structure and a characteristic chemical composition, crystal form, and physical properties.
mineralogy	The study of minerals. Also the formation, occurrence, properties, and composition of the minerals that make up a rock.
Miocene	An epoch of geologic time in the Tertiary Period, after the Oligocene Epoch and before the Pliocene Epoch.
mitigation	(1) Avoiding the impact altogether by not taking a certain action or parts of an action. (2) Minimizing impacts by limiting the degree or magnitude of the action and its implementation. (3) Rectifying the impact by repairing, rehabilitating, or restoring the affected environment. (4) Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action. (5) Compensating for the impact by replacing or providing substitute resources or environments.
mixing height (or depth)	The height above the surface of the earth defining a layer where vigorous vertical mixing of air occurs; this mixing layer represents the vertical extent to which pollutants can be mixed in the atmosphere.

modal analysis	The analysis of the actual mineral composition of a rock, usually expressed in weight or volume percentage. See "conceptual model," "tectonic model."
model	A conceptual description and the associated mathematical representation of a system, component, or condition. It is used to predict changes in the system, component, or condition in response to internal or external stimuli as well as changes over time and space. An example is a hydrologic model to predict ground-water travel or radionuclide transport from the waste-emplacement area to the accessible environment.
modeling, hydrologic	See "hydrologic modeling."
monitoring	Routine measuring of the quantity and type of radionuclide releases from a waste-management facility or measuring of the changes in the physical, chemical, or biological characteristics of the site and the surrounding area.
modified Mercalli scale	An earthquake-intensity scale with 12 divisions ranging from I (not felt by people) to XII (damage nearly total); commonly abbreviated MM.
modulus of deformation	A term used for materials that deform in a manner other than according to Hooke's law; also called "modulus of elasticity" (see "Hooke's law").
modulus of elasticity	See "elastic modulus."
monolithic structure	A structure formed or composed of rock material without joints or seams.
moraine	A mound, ridge, or other accumulation of unsorted, unstratified rock material left at the margins of a retreating glacier.
mordenite	One of the zeolite minerals which generally has a sodium-rich composition and is frequently associated with clinoptilolite, having essentially the same occurrence.
morphology	The study of topographic features; the form of land.
muck	Broken rock that results from mining.
mudstone	A dark-gray, fine-grained shale that decomposes into mud when exposed to the atmosphere.
multibarrier system	A system of natural and engineered barriers, operating independently or relatively independently, that acts to contain and isolate the waste.

multiwell aquifer test	A test to determine an aquifer's capacity; it involves adding or withdrawing measured quantities from more than one well and measuring the resulting changes in hydraulic head.
natural background radiation	See "background radiation."
natural barrier	The physical, mechanical, chemical, and hydrologic characteristics of the geologic environment that, individually and collectively, act to minimize or preclude radionuclide transport.
natural gamma log	A log of the natural radioactivity of the rocks traversed in a borehole obtained by measuring naturally emitted gamma rays.
natural system	A host rock suitable for repository construction and waste emplacement and the surrounding rock formations. Includes natural barriers that provide containment and isolation by limiting radionuclide transport through the geohydrologic environment to the biosphere and provides conditions that will minimize the potential for human interference in the future.
near field	The region where the natural geohydrologic system has been significantly perturbed by the excavation of the repository and the emplacement of the waste.
neutron log	A radioactivity log that measures the intensity of neutrons or gamma rays produced when rocks around a borehole are bombarded by neutrons from a synthetic source.
neutron probe	A probe used to measure the intensity of radiation for a neutron log.
Nevada Test Site	An area in Clark and Nye Counties in southern Nevada; it is dedicated to the underground testing of nuclear weapons.
noble gases	A group of gases that includes helium, neon, argon, krypton, xenon, and sometimes radon. Also known as inert gases, these gases have great stability and extremely low reaction rates.
nonconformity	An unconformity in which stratified rocks above the surface rest on unstratified, older rocks.
nonradiological risk	A risk from sources other than exposure to radiation.
normal fault	A fault in which the hanging wall appears to have moved downward relative to the footwall. The angle of the fault is usually 45 to 90 degrees.

occupational dose The radiation dose received by a person in a restricted area or in performing work duties involving exposure to radiation.

operational phase The period of time from the receipt of the first waste at the site of the repository to closure and decommissioning.

orogenic Of or pertaining to the process of mountain formation, especially by folding of the earth's crust.

outcrop The part of a geologic formation or structure that appears at the surface of the earth.

overburden Loose soil, sand, gravel, or other unconsolidated material that overlies bedrock.

overcoring A process that determines stress components in a rock mass. The process consists of drilling a small-diameter borehole and inserting deformation-sensing devices. A larger hole is then drilled concentrically with the first hole, which relieves the stress in the rock cylinder. The measured deformations are related to stresses through elastic relationships.

overthrust A low-angle thrust fault of a large scale, with displacement generally measured in kilometers.

oxidation-reduction reaction A chemical reaction in which one or more electrons are transferred between two or more chemical constituents of the system.

package See "waste package."

packer A device used in drilled holes to isolate one part of a borehole from another in order to carry out studies of particular formations or parts thereof.

packer-injection tests A series of tests whereby a liquid (usually water) or gas is injected into a sealed off or isolated portion of a borehole or well to obtain data on formation permeability, fracture flow, and the like.

paleoclimate A climate of the geologic past.

paleoecology The study of the relationship between ancient organisms and their environment.

paleohydrology The study of ancient hydrologic features preserved in rock.

paleomagnetism The study of the natural remnant magnetization of the earth to determine the intensity and direction of the earth's magnetic field in the geologic past.

paleontology	The study of life of the geologic past based on fossilized plant and animal remains.
paleosol	A buried soil of the geologic past.
Paleozoic	The era of geologic time, from the end of the Precambrian to the beginning of the Mesozoic or from about 570 million to 225 million years ago.
paludal	Pertaining to a marsh or swamp.
palynology	The study of spores, pollen, and microorganisms that occur in sediments.
panel	A collection of underground rooms connected by a common access and common ventilation corridors.
Paradox Basin	A 25,900-square-kilometer (10,000-square-mile) area in southeastern Utah and southwestern Colorado; it is underlain by bedded salt and a series of salt-core anticlines. The Davis Canyon site is in the Paradox Basin.
particulates	Finely divided particles suspended in a gaseous medium, such as dust in air.
Pasco Basin	A structural and topographic basin in the western Columbia Plateau. The Hanford Site and the reference repository location are in the Pasco Basin.
passive institutional controls	(1) Permanent markers placed at a disposal site. (2) Public records or archives. (3) Federal Government ownership or control of land use. (4) Other methods of preserving knowledge about the location, design, or contents of a disposal system.
pathway	As related to waste disposal, possible or potential routes by which wastes might reach the accessible environment.
pedology	The study of the morphology, origin, and classification of soils.
perched ground water	Unconfined ground water separated from an underlying body of ground water by an unsaturated zone. Perched ground water is supported by a perching bed whose permeability is so low that water percolating downward through it is not able to bring water in the underlying unsaturated zone above atmospheric pressure.
percolate	In hydrology, the passage of a liquid through a porous substance; e.g., the movement of water, under hydrostatic pressure developed naturally underground, through the interstices and pores of the rock or soil; i.e., the slow seepage of water through soils or porous deposits.

performance assessment	Any analysis that predicts the behavior of a system or system component under a given set of constant or transient conditions. For the repository, such an analysis identifies the events and processes that might affect the disposal system, examines their effects on its barriers, and estimates the probabilities and consequences of the events.
performance confirmation	A program of test, experiments, and analyses required by the Nuclear Regulatory Commission and conducted to evaluate the accuracy and adequacy of the information used to determine reasonable assurance that the postclosure performance objectives can be met.
performance criterion	A criterion establishing qualitative operational, safety, or environmental limits.
periglacial	Pertaining to the areas, conditions, processes, and deposits marginal to an ice sheet or glacier.
permanent closure	See "closure."
permeability	The capacity of a medium like rock, sediment, or soil to transmit ground water. Permeability depends on the size and shape of the pores in the medium and the manner in which the pores are interconnected.
Permian Basin	A region in the Central United States where, during Permian time 280 to 225 million years ago, there were many shallow seas that laid down vast beds of salt and other evaporites. The Deaf Smith site is in the Permian Basin.
permissible dose	That dose of ionizing radiation that, in light of present knowledge, carries negligible probability of causing a severe somatic injury or a genetic effect.
petrography	The branch of geology that deals with the description and systematic classification of rocks, especially igneous and metamorphic rocks and especially by the microscopic examination of thin sections.
petrology	The branch of geology that deals with the origin, occurrence, structure, and history of rocks.
pH	A measure of the acidity or alkalinity of a solution.
phenocryst	A term applied to any large, conspicuous crystal in an igneous rock.
phosphatic rock	Any rock that contains one or more phosphatic minerals, especially apatite.
photogrammetry	The science and art of obtaining reliable measurements from photographs.

physiography	The descriptive study of landforms as opposed to geomorphology, which is the interpretive study of land forms.
physiographic province	A region in which all parts are similar in geologic structure and climate and which consequently had a unified geomorphic history.
piezometer	A tube or pipe in which the elevation of water level can be determined. A piezometer must be sealed along its length, and it must be open to water flow at the bottom and to the atmosphere at the top.
piezometric surface	See "potentiometric surface."
pillar	A solid mass of rock left standing to support a mine roof.
plasticity	The property of a material that enables it to undergo permanent deformation without appreciable volume change or elastic rebound without rupture.
plate bearing test	A procedure performed in small tunnels or adits to measure the deformation characteristics of a rock mass.
platform	A general term for any level or nearly level surface under water.
playa	The lowest central portion of an arid basin that is dry and totally barren most of the time, but is occasionally flooded. Clay and silt are the principal constituents, often resulting from lakes formed in Pleistocene time.
Pleistocene	The first epoch before the Holocene of the Quaternary Period.
Pliocene	The latest epoch of geologic time in the Tertiary Period, preceded by the Miocene Epoch and followed by the Pleistocene Epoch.
plug (geologic)	(1) The vertical pipe-like magnetic body representing the conduit of a former volcanic vent. (2) A crater filling of lava, the surrounding material of which has been removed by erosion. (3) A mass of clay, sand, or other sediment filling the part of a stream channel abandoned by the formation of a cutoff.
plug (shaft or borehole)	A watertight seal in a shaft formed by removing the lining and inserting a concrete and/or metal dam, or by placing a plug of clay over ordinary debris used to fill the shaft up to the location of the plug.

pluvial	Said of a geologic episode, change, process, deposit, or feature resulting from the action or effects of rain. Also said of a climate characterized by relatively high amounts of precipitation. More broadly, pertaining to rain or other form of precipitation.
point source	A source of effluents small enough to be treated as if it were a point.
poison	Any material that has a high neutron-absorption cross section and, by absorbing neutrons unproductively, removes them from the fission chain reaction, thus decreasing the radioactivity.
Poisson's ratio	The ratio of the lateral unit strain to the longitudinal unit strain in a body that has been stressed longitudinally within its elastic limit.
population center	A densely populated area of 25,000 or more inhabitants.
population dose	The sum of the radiation doses received by the individual members of a population exposed to a particular source or event. It is expressed in units of man-rem.
pore	Any small open space, generally one that admits the passage or absorption of liquid, within the rock or soil.
porosity	The ratio of the total volume of interstices in rock or soil to its total volume, usually expressed as a percentage.
porosity log	A record of pore volume per unit volume of formation; it is made from a sonic log, density log, neutron log, or resistivity log.
porphyritic	A texture of igneous rock in which large crystals are set in a finer groundmass that may be crystalline or glassy or both.
postclosure	Of or pertaining to the time, conditions, or events after the closure of the repository.
potable water	Water that is safe and palatable for human use.
potentially acceptable site	Any site at which, after geologic studies and field mapping but before detailed geologic data gathering, the DOE undertakes preliminary drilling and geophysical testing for the definition of site location.
potentially adverse condition	A condition that is presumed to detract from expected system performance unless further evaluation, additional data, or the identification of compensating or mitigating factors indicates that its effect on the expected performance of the repository system is acceptable.

potentially disruptive processes and events	Natural processes and events or processes and events initiated by human activities, affecting the geologic setting that are judged to be reasonably unlikely during the period over which the intended performance objective must be achieved, but are nevertheless sufficiently credible to warrant consideration.
potentiometric surface	The surface to which water from a given aquifer will rise by hydrostatic pressure. This surface is usually represented as a contour map in which each point tells how high the water would rise in a well tapping that aquifer at that point.
Precambrian	All geologic time, and its corresponding rocks, that elapsed before the beginning of the Paleozoic era (the Paleozoic era began about 570 million years ago).
precipitation (geochemical)	The process by which mineral constituents are separated from magma or from a solution by evaporation to form igneous rocks.
preclosure	Of or pertaining to the time, activities, operations, and conditions before and during the closure of the repository.
pressurized water reactor	A nuclear reactor that uses pressurized water to generate electricity.
pre-waste-emplacment	Of or pertaining to geologic conditions before waste emplacement.
primary sector	The businesses that predominantly sell their goods and services to individuals and businesses outside the local economy. (See "secondary sector.")
prime farmland	Land with the best physical and chemical characteristics for producing agricultural crops with minimum use of fuel, fertilizers, pesticides, and labor and without intolerable soil erosion, as determined by the Secretary of Agriculture pursuant to the Farmland Protection Policy Act of 1982 (Public Law 97-98). Prime farmland includes land that has these characteristics and is being used to produce livestock and timber, but it excludes land already in, or committed to, urban development or water storage.
probable maximum flood	A statistical representation of the greatest flood expected ever to occur at a specific location.
probable maximum precipitation	A statistical representation of the most precipitation that can reasonably be expected in a given area.
protected area	An area encompassed by physical barriers and to which personnel access is controlled.

protected species	Plants and animals officially listed by the U.S. Fish and Wildlife Service. Species listed by the States as rare, threatened, or endangered are not included unless they are also on the Federal list.
pumice	A light-colored, cellular, glassy rock commonly having the composition of rhyolite.
pyroclast	An individual particle ejected during a volcanic eruption.
quadrangle (geologic)	A tract of country represented by one of a series of map sheets published by the U.S. Geological Survey.
qualified site	A site that, having been characterized, is considered to be technically suitable for a repository.
qualifying condition	A condition that must be satisfied for a site to be considered acceptable with respect to a specific siting guideline.
quality assurance	All the planned and systematic actions necessary to provide adequate confidence that a structure, system, or component is constructed to plans and specifications and will perform satisfactorily.
quality control	Quality-assurance actions that provide a means to control and measure the characteristics of an item, process, or facility to established requirements.
quartz	Crystalline silica (SiO_2); an important rock-forming mineral.
quartzite	A metamorphic rock consisting mainly of quartz grains of equal size, formed by the recrystallization of sandstone by regional or thermal metamorphism.
Quaternary faults	Faults that formed or experienced movement during the Quaternary Period.
Quaternary Period	The second part of the Cenozoic Era (after the Tertiary), beginning about 1.8 million years ago and extending to the present.
rad	The basic unit of the absorbed dose of ionizing radiation. A dose of 1 rad equals the absorption of 100 ergs of radiation energy per gram of absorbing material.
radiation (ionizing)	Particles and electromagnetic energy emitted by nuclear transformations that are capable of producing ions when interacting with matter; gamma rays and alpha and beta particles are primary examples.

radiation zone	An area that contains radioactive materials or radiation field in quantities significant enough to require the control of personnel entry to the area.
radioactive decay	See "decay."
radioactive material	In general, any material that spontaneously emits nuclear particles or rays from the nuclei of its atoms.
radioactive waste	High-level radioactive waste, spent nuclear fuel, and other radioactive materials that are received for emplacement in a geologic repository.
radiological risk	A risk derived from exposure to radioactive materials.
radiolysis	The decomposition (splitting) of a chemical molecule (often the water molecule) by exposure to radiation.
radiometric dating	The calculation of the age of a material by a method that is based on the decay of radionuclides that occur in the material.
radionuclide	An unstable radioactive isotope that decays toward a stable state at a characteristic rate by the emission of ionizing radiation.
radionuclide retardation	The process or processes that cause the time required for a given radionuclide to move between two locations to be greater than the ground-water-travel time because of physical and chemical interactions between the radionuclide and the geohydrologic unit through which the radionuclide travels.
rain shadow	A very dry region on the lee side of a topographic obstacle, usually a mountain range, where the rainfall is noticeably less than that on the windward side.
reasonably achievable	Mitigation measures or courses of action shown to be reasonable considering the costs and benefits in accordance with the National Environmental Policy Act of 1969. (See "as low as reasonably achievable.")
reasonably available technology	Technology which exists and has been demonstrated, or for which the results of any requisite development, demonstration, or confirmatory testing efforts before application will be available within the required time periods.
reasonably foreseeable releases	Releases of radioactive wastes to the accessible environment that are estimated to have more than one chance in 100 of occurring within 10,000 years.

recharge (hydrologic)	The process by which water is absorbed and added to the zone of saturation, either directly into a geologic formation, indirectly by way of another formation, or indirectly through unconsolidated sediments.
recharge area	In ground-water hydrology, the area where surface water enters an aquifer.
redox	See "oxidation-reduction reaction."
reduction (chemical)	A decrease in the oxidation state of an element or chemical compound.
redundant equipment or system	Any piece of equipment or any system that duplicates the essential function of any other piece of equipment or system and can perform the entire function regardless of the operating state of the other.
regulated area	An area to which access is limited or controlled.
regulatory agency	The government agency responsible for regulating the use of sources of radiation or radioactive materials or emissions and responsible for enforcing compliance with such regulations.
regulatory guide	One of a series of official Nuclear Regulatory Commission guides prescribing standards and recommendations for nuclear facilities.
relative porosity	The ratio of the aggregate volume of interstices in a rock or soil to its total volume. It is usually stated as a percentage.
release limit	A regulatory limit on the concentration or amount of radioactive material released to the environment; usually expressed as a radiation dose.
rem	A unit dose of ionizing radiation that has the same biological effect as 1 roentgen of x-rays; 1 rem approximately equals 1 rad for x-, gamma, or beta radiation. Thus, a rem is a unit of individual dose that allows a comparison of the effects of various radiation types as well as quantities.
remotely handled transuranic waste	Transuranic waste that requires shielding in addition to that provided by its container in order to protect people nearby.
repository	See "geologic repository."
repository closure	See "closure."

repository construction	All excavation and mining activities associated with the construction of shafts, shaft stations, rooms, and necessary openings in the underground facility, preparatory to radioactive-waste emplacement, as well as the construction of necessary surface facilities, but excluding site-characterization activities.
repository horizon	The horizontal plane within the host rock where the location of the repository is planned.
repository operation	All of the functions at the site leading to and involving radioactive-waste emplacement in the underground repository, including receiving, transporting, handling, emplacing, and, if necessary, retrieving the waste.
repository support facilities	All permanent facilities constructed to support site characterization and repository construction, operation, and closure, including surface structures, utility lines, roads, railroads, but excluding the underground repository.
repository system	The geologic setting at the site, the waste package, and the repository, all acting together to contain and isolate the waste.
reprocessing	See "fuel reprocessing."
residual saturation	The minimum saturation that occurs due to gravitational forces alone in the absence of recharge.
residual uncertainty	Those inherent uncertainties in data, modeling, and assumed future conditions that cannot be eliminated.
restricted area	Any area to which access is controlled by the DOE for purposes of protecting of individuals from exposure to radiation and radioactive materials before repository closure, but not including any areas used as residential quarters, although a separate room or rooms in a residential building may be set apart as a restricted area.
retention pond	An earthen structure designed to hold stormwater runoff; sometimes used to mean an evaporation pond.
retrievability	The capability to remove waste from its place of isolation in accordance with preestablished criteria for the method and the rate of removal.
retrieval	The act of intentionally removing radioactive waste before repository closure from the underground location at which the waste had been previously emplaced for disposal.
reverse fault	A fault in which the hanging wall appears to have moved upward relative to the footwall.

rhyolitic	Characteristic of a group of extrusive igneous rocks, generally porphyritic and exhibiting flow texture with crystals of quartz and alkali feldspar in a glassy to cryptocrystalline groundmass (rhyolite).
Richter magnitude	See "Richter scale."
Richter scale	A scale for measuring the energy released by an earthquake. It was devised in 1935 by the seismologist C. F. Richter.
rift (geologic)	A long, narrow trough of regional extent, bounded by normal faults, often associated with volcanism.
right-lateral fault	A fault, the displacement of which is right-lateral separation. In plan view, the apparent movement of the side opposite the observer is to the right.
right-lateral offset	See "right-lateral fault."
riparian	Relating to or living or located on the bank of a natural water course (e.g., a river).
risk	The product of the probability and the consequences of an event.
rock bolt	A bar, usually constructed of steel, that is anchored into predrilled holes in rock as a support device.
rock burst	A sudden yielding that occurs when a volume of rock is strained beyond its elastic limit and the accompanying failure is such that the accumulated energy is released instantaneously. A rock burst can vary from the splitting off of small slabs of rock from a mine wall to the collapse of large pillars, roofs, or other massive parts of a mine.
rock-mass quality	A description of the physical characteristics and mechanical behavior of the rock mass. Rock-mass quality classifications are applied empirically to estimate requirements for underground-excavation support and mechanical properties like the strength and deformation modulus of the rock mass.
room-and-pillar mining	A system of mining in which the rock is mined in rooms separated by pillars of undisturbed rock left for roof support.
rubble	Loose, unconsolidated rock consisting mostly of large, angular rocks intermixed with a small amount of soil or earthy material.

rulemaking	Process of formulating specific regulations governing a particular matter.
salt	The common mineral sodium chloride (NaCl) and any impurities in it.
salt creep	See "creep."
sandstone	Variously colored sedimentary rock composed mainly of sandlike quartz grains cemented by lime, silica, or other materials.
saturated zone	That part of the earth's crust beneath the water table in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric.
scabland	An elevated area, underlain by flat-lying basalt flows, with a thin soil cover and sparse vegetation that is crossed by coulees.
scaling	The removal of loose rock from a newly blasted wall or roof.
scanning- transmission electron microscope	A type of electron microscope that scans with an extremely narrow beam of electrons transmitted through the sample; the detection apparatus produces an image whose brightness depends on the atomic number of the sample.
scarification	The process of breaking up and loosening the surface of a material.
scenario	A particular chain of hypothetical circumstances often used in performance analysis to model possible events.
scenario analysis	Analytical process that attempts to quantify the probabilities and consequences of a postulated sequence of events.
scouring	Erosion, especially by moving water.
screening	The process of evaluating an area on the basis of criteria or guidelines to identify places that best fulfill the criteria or guidelines.
seal	An engineered barrier to prevent radionuclide migration or the intrusion of undesirable substances.
secondary compression	The reduction in volume of sediments under constant pressure that results from changes in the internal structure of the sediments.
secondary sector	The sectors of the economy that serve local residents and businesses. (See "primary sector.")

sedimentary rock	Rock formed of sediment, especially (a) clastic rocks (e.g., conglomerates, sandstone, and shales) formed of fragments of other rock transported from their sources and deposited in water and (b) rocks formed by precipitation from solution (e.g., rock salt and gypsum) or from the secretions of organisms (e.g., most limestones).
seismic	Pertaining to, characteristic of, or produced by earthquakes or earth vibrations.
seismic reflection line	A line on the earth's surface along which a seismic reflection survey is conducted.
seismic reflection survey	A survey based on measurement of the travel times of waves that originate from an artificially produced disturbance and are reflected back to the surface at nearly vertical incidence from boundaries separating media of different elastic-wave velocities.
seismic refraction survey	A survey based on the measurement of the travel times of seismic waves that have moved nearly parallel to the bedding in high-velocity layers.
seismic survey	Seismic data gathered from an area.
seismicity	The occurrence of earthquakes or the spatial distribution of earthquake activity. Also the phenomenon of earth movement.
seismometer	An instrument that receives seismic impulses and converts them into electrical voltage or otherwise makes them evident. Also known as a geophone.
shaft	With regard to a geologic repository, the penetration of the natural isolation barrier to provide access to subsurface facility; it is usually of limited cross-sectional area compared to its depth. A more common definition is a manmade hole, either vertical or steeply inclined, that connects the surface with the underground workings of a mine or excavation. The difference between a shaft and a borehole is primarily in size and use.
shaft liner	A structural lining usually made of steel, concrete, or timber that provides safe rock support and aids in preventing ground water from entering the shaft.
shaft pillar	An undisturbed buffer zone surrounding a shaft of sufficient area, so that any possible subsidence in nearby mined areas will not disturb the integrity of the shaft facility.
shaft seal system	The devices, mechanisms, or materials used or emplaced between the shaft liner and the rock wall during operation or shaft closure to retard the flow of liquid or gas.

shaft station	A horizontally excavated opening of a shaft at a desired depth.
shale	A fine-grained detrital sedimentary rock formed by the compaction of clay, silt, or mud.
shear	(1) A strain that causes contiguous parts of a body to slide relative to each other in a direction parallel to their plane of contact. (2) Surfaces and zones of failure by shear or surfaces along which differential movement has taken place.
shear resistance	The internal resistance of a body to shear stress, typically including a frictional part and a part independent of friction called "cohesion." Also called "shear strength."
shear zone	A tabular zone of rock that has been crushed and brecciated by many parallel fractures due to shear strain.
sheave	A large, pulley-type wheel at the top of the headframe that carries the hoist rope.
shield rocks	Areas of exposed basement rocks in a craton commonly with a very gently convex surface, surrounded by sediment-covered platforms.
shielding	The material interposed between a source of radiation and personnel to protect against radiation exposure; commonly used shielding materials are concrete, water, and lead.
shipping cask	A large, heavily shielded vessel for transporting fuel assemblies and radioactive waste. The cask provides physical protection to the contents and radiation protection to its surroundings. Radioactive waste is transported to the repository in shipping casks.
shotcrete	Cement-based compounds sprayed onto mine surfaces to prevent erosion by air and moisture and onto rock surfaces to stabilize against minor rock falls. Also used to prevent dehydration and decrepitation.
shrub-steppe	Distinguished from a true steppe by the presence of forbes, shrubs, and a few trees in an extensive grassland area. Generally not as dry as a steppe.

significant source of ground water	As defined in 40 CFR Part 191, an aquifer that (1) is saturated with water having less than 10,000 milligrams per liter of total dissolved solids, (2) is within 770 meters (2,500 feet) of the land surface, (3) has a transmissivity greater than 3×10^{-5} square meter per second (200 gallons per foot per day), provided that any formation or part of a formation included within the source of ground water has a hydraulic conductivity greater than 1×10^{-6} meter per second (2 gallons per square foot per day), and (4) is capable of continuously yielding at least 1,600 liters per hour (10,000 gallons per day) to a pumped or flowing well for a period of at least a year; or an aquifer that provides the primary source of water for a community water system.
silica	A chemically resistant oxide of silicon (SiO_2).
silicification	The introduction of, or replacement by, silica, generally resulting in the formation of fine-grained quartz, chalcedony, or opal, which may fill pores and replace existing minerals.
sill (geologic)	A tabular igneous intrusion that parallels the planar structure of the surrounding rock.
silt	A sedimentary material consisting of fine mineral particles intermediate in size between sand and clay.
siltstone	Stone composed of hardened silt.
sinkhole	An opening at the earth's surface caused by the collapse of rock above a solution zone where ground water has moved along a joint or fracture system and has washed out or dissolved underlying material, such as limestone.
site	A potentially acceptable site or a candidate site, as appropriate, until such time as the controlled area has been established, at which time the site and the controlled area are the same.
site characterization	Activities, whether in the laboratory or in the field, undertaken to establish the geologic conditions and the ranges of the parameters of a candidate site relevant to the location of a repository, including borings, surface excavations, excavations of exploratory shafts, limited subsurface lateral excavations and borings, and in situ testing needed to evaluate the suitability of a candidate site for the location of a repository, but not including preliminary borings and geophysical testing needed to assess whether site characterization should be undertaken.

siting	All of the exploration, testing, evaluation, and decisionmaking associated with site screening, site nomination, site recommendation, and site approval for characterization or repository development.
siting guidelines	General guidelines for siting geologic repositories; issued by the Department of Energy as 10 CFR Part 960.
slabbing	A stress-induced failure mechanism of the rock around an excavation.
slash	A mining technique in which a large-diameter drilled hole is enlarged by using the drill-and-blast method.
slickensides	Polished and smoothly striated surfaces that result from friction along a fault plane.
slip	The relative displacement of formerly adjacent points on opposite sides of a fault, measured in the fault surface.
slough	Fragments of rock material from the wall of a borehole that are washed out of the hole with the return pipeline.
sloughing	The falling of loosened rock from the roof or walls of and underground excavation.
slump (geologic)	The downward slipping of a mass of rock or unconsolidated material of any size, moving as a unit or as several subsidiary units, usually with backward rotation on a more or less horizontal axis parallel to the cliff or slope from which it descends.
slurry	A fluid mixture of water and finely divided material.
smectite	A group of expanding-lattice clay minerals. These minerals are common in soils, sedimentary rocks, and some mineral deposits and are characterized by swelling in water and extreme colloidal behavior.
solubility	The amount of substance (i.e., an element or compound) that can be dissolved in a given amount of solvent.
solute	A substance dissolved in another substance, usually the component of a solution present in the lesser amount.
sonic log	A geophysical log made by an instrument, lowered and raised in a borehole or well, that continuously records, as a function of depth, the velocity of sound waves as they travel over short distances in the adjacent rocks. The log reflects lithologic changes.

sorption	The binding, on a microscopic scale, of one substance to another, such as by adsorption or ion exchange. Here "sorption" is used for the sorption of dissolved radionuclides onto aquifer solids or waste-package materials by chemical or physical forces.
sorptive capacity	The measure of a material's ability to sorb specific constituents from a liquid as it passes through the material.
source term	The types and amounts of radionuclides that make up the source of a potential release of radioactivity.
specific activity	The measure of radioactivity as a function of mass. The unit of specific activity is curie per gram.
specification	A concise statement of a set of requirements prescribing materials, dimensions, or workmanship for something to be built or manufactured.
specific heat	The quantity of heat necessary to raise the temperature of 1 gram of a given substance 1 degree Celsius.
specific yield	The ratio of the volume of water that a given mass of saturated rock or soil will yield by gravity to the volume of that mass.
spent fuel	Nuclear fuel that has been removed from a reactor after irradiation and has not been reprocessed to recover uranium and plutonium.
spherulitic	Said of a rock composed of numerous rounded or spherical masses of needlelike crystals, radiating from a central point.
spoils	The debris or waste material from a mine. The rock and other natural materials brought up to the surface during mining. Also called "mined materials" or "mined rock."
stability, repository	The condition resulting from the nature and rates of natural processes affecting the site during the recent geologic past and the expectation that they will be relatively slow and will not significantly change during the next 10,000 years or jeopardize the isolation of the waste. As defined in 10 CFR Part 60, the nature and rates of natural processes (e.g., erosion and faulting) have been and are projected to be such that their effects will not jeopardize the isolation of the waste.
stability of rock structure	The capability of an opening at depth to retain its original shape for a length of time. Stability is related to the quality of the rock mass around the opening, including slabbing and fracture.

standard metropolitan statistical area (SMSA)	One or more contiguous counties containing at least one city of 50,000 inhabitants or more. Additional counties have to meet criteria related to metropolitan character and socioeconomic integration with the central city.
steel sets	Support beams used in mine roofs and walls.
steppe	An extensive treeless grassland area that is developing in the semiarid midlatitudes of southeastern Europe and Asia. Also used to describe similar areas in other parts of the world.
stochastic model	A model whose inputs are uncertain and whose outputs are therefore also uncertain and must be described by probability distributions.
storage coefficient	The volume of water an aquifer releases from, or takes into storage, per unit surface area of the aquifer and per unit change in head.
storativity	The volume of water released from storage in a vertical column of 1 square foot when the water table or other piezometric surface declines 1 foot. In an undefined aquifer, it is approximately equal to the specific yield.
strain	(1) Change in the shape or volume of a body as a result of stress. (2) A change in the relative configuration of the particles of a substance.
stratigraphic setting	The characteristics of the rock layers or other units in the geologic environment.
stratigraphy	The branch of geology that deals with the definition and interpretation of the rock strata, the conditions of their formation, character, arrangement, sequence, age, distribution, and especially their correlation by the use of fossils and other means of identification.
stratum	A single bed or layer of rock regardless of thickness.
stress	In a solid, the force per unit area acting on any surface within it and variously expressed as pounds or tons per square inch, or dynes or kilograms per square centimeter; also, by extension, the external pressure that creates the internal force.
strike	The direction or trend of a structural surface (e.g., a bedding or fault plane) as it intersects the horizontal.
strike-slip fault	A fault in which the net slip is horizontal or parallel to the strike of the fault (see also "dip-slip fault").
stringer	A narrow vein or irregular filament in a rock mass of different material.

student's t test	A standard statistical method used for hypothesis testing and normally used with a sample size of less than 30.
subsidence	Sinking or downward settling of the earth's surface; not restricted in rate, magnitude, or area involved.
subsurface facility	See "underground facility."
sump	A pit or depression serving as a drain or reservoir for liquids.
surface facilities	Repository support facilities in the restricted area.
surface water	Any waters on the surface of the earth, including fresh and salt water, ice, and snow.
surge capacity	The capacity to accommodate radioactive materials by temporary storage at the repository.
system	See "repository system."
system performance	The complete behavior of a repository system in response to the conditions, processes, and events that may affect it.
talus	Loose rock fragments of any size or shape derived from, and lying at, the base of a steep slope.
tectonic	Of, or pertaining to, the forces involved in tectonics or the resulting structures or features.
tectonic activity	Movement of the earth's crust such as uplift and subsidence and the associated folding, faulting, and seismicity.
tectonic breccia	A breccia formed as the result of crustal movements, usually developed in brittle rocks. Slickensides are commonly associated with tectonic breccia, and varying amounts of claylike gouge may be present.
tectonic features	Features such as fault gouge, faulted, and folded rock.
tectonic fractures	Fractures that may or may not have slickensides on their adjoining surfaces and are commonly associated with tectonic breccias. Includes fractures across which no measurable movement has occurred.
tectonic model	A nonnumerical, descriptive theory or concept that incorporates geological, geophysical, and geodetic data into a satisfactory explanation of the evolution of stress and strain in the earth's crust; it can be used to make estimates of future crustal processes.

tectonic province	A region of the earth's crust with relatively consistent structural geologic features.
tectonism	Crustal movement produced by earth forces, such as the formation of plateaus and mountain ranges; the structural behavior of an element of the earth's crust.
tectonics	A branch of geology dealing with the broad architecture of the outer part of the earth; that is, the regional assembling of structural or deformational features, a study of their mutual relations, their origin, and their evolution.
tensile strength	The ability of a material to resist a stress tending to stretch it or to pull it apart.
Tertiary	The earlier of the two geologic periods that make up the Cenozoic Era, extending from 65 million to 1.8 million years ago.
thermal conductivity	A measure of the ability of a material to conduct heat.
thermal decrepitation	The shattering of a rock mass or rock sample caused by the heat-induced buildup of excessive pressures in contained fluids.
thermal expansion	The increase in linear dimensions that occurs when materials are heated.
thermal gradient	The rate of change in temperature with distance.
thermal loading	The application of heat to a system, usually measured in watt-density. The thermal loading for a repository is the watts per acre produced by the radioactive waste in the active disposal area.
thermoluminescent dosimeter	A type of radiation measuring device that contains thermoluminescent material that emits light when subjected to heat. The amount of light emitted is directly proportional to the radiation dose absorbed by the chip.
threatened species	Any plant or animal species protected by Public Law 93-205 that is likely to become endangered in the foreseeable future throughout all or a portion of its range.
thrust fault	A fault with a dip of 45 degrees or less in which the hanging wall appears to have moved upward relative to the foot wall.
to the extent practicable	The degree to which an intended course of action is capable of being effected in a manner that is reasonable and feasible within a framework of constraints.

topography	The branch of geology dealing with the configuration of the land surface, including its relief and the position of natural and man-made features. Also used synonymously with "terrain."
tortuosity	The inverse ratio of the length of a rock specimen to the length of the equivalent path of water within it.
tracer testing	A procedure in which a soluble substance (tracer) is added to ground-water at one location and its movement to another location is observed. Tracer testing is a technique by which ground-water flow directions and velocities and other hydrologic properties of rocks can be estimated.
transfer cask	A cask that provides shielding for the waste disposal container as it is transferred from the waste-handling buildings for emplacement underground.
transgressive sea	A sea that has encroached on the land.
transmissivity	The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It equals the hydraulic conductivity multiplied by the thickness of the aquifer.
transport path	A route along which radionuclides could migrate.
transuranic waste	Waste containing more than a specific concentration of alpha-emitting radionuclides (including uranium-233 and its daughter products) of long half-life and high specific radiotoxicity. This concentration is currently defined as more than 100 nanocuries per gram of waste.
transuranics	Elements with an atomic number higher than 92. They do not normally occur in nature and have to be produced artificially from uranium.
tridymite	A mineral, SiO_2 . It is a high-temperature form of quartz and usually occurs as minute, tabular, white or colorless crystals or scales in cavities in acidic volcanic rocks.
tritium	A radioactive isotope of hydrogen with two neutrons and one proton in the nucleus.
tubbing	Cast-iron liner plates for shafts, fabricated to specification, that bolt together to give support to rock.
tufa	A sedimentary rock composed of calcium carbonate, formed by evaporation as an incrustation around the mouth of a spring, along a stream, or around a lake.

tuff	A rock formed of compacted volcanic ash and dust.
tuffaceous	Said of sediments containing up to 50 percent tuff.
unconfined aquifer	An aquifer containing ground water that has a water table or upper surface at atmospheric pressure.
unconformity (geologic)	A break or gap in the geologic record, such as an interruption in the normal sequence of deposition of sedimentary rocks, or a break between eroded metamorphic rocks and younger sedimentary strata.
underground facility	The underground structure and the rock required for support, including mined openings and backfill materials, but excluding shafts, boreholes, and their seals.
unit of local government	Any borough, city, county, parish, town, township, village, or other general-purpose political subdivision of a State.
unrestricted area	Any area that is not controlled for the protection of individuals from exposure to radiation and radioactive materials.
unsaturated zone	The zone between the land surface and the water table. Generally, water in this zone is under less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or perched-water bodies, the water pressure locally may be greater than atmospheric.
uplift (geologic)	(1) The process that results in the elevation of a portion of the earth's crust. (2) A structurally high area in the crust produced by movements that have raised or upthrust the rocks, as in a dome or an arch.
upwarping	The uplift of a regional area of the earth's crust, usually as a result of the release of isostatic pressure (e.g., the melting of an ice sheet).
urban area	As defined for use in the 1980 census, incorporated and unincorporated places of 2,500 inhabitants or more.
vadose water	Water of the zone of aeration (unsaturated zone). Also known as "suspended water."
vadose zone	The unsaturated region of soil or the zone of aeration between the ground surface and the water table.
validation of computer codes and models	A process whose objective is to ascertain that the code or model indeed reflects the behavior of the real world.

vent system	A group of generally parallel fissures from which lava came to the surface.
verification of computer codes and models	Testing a code with analytical solutions for idealized boundary-value problems. A computer code will be considered verified when it has been shown to solve the boundary-value problems with sufficient accuracy.
very near field	The waste package and the rock within approximately 3 feet of the waste packages emplaced in a repository.
very unlikely releases	Releases of radioactive wastes to the accessible environment that are estimated to have between one chance in 1,000 and one chance in 10,000 of occurring within 10,000 years.
vesicle	A small cavity in an igneous rock, formed by the expansion of a bubble of gas or steam during the solidification of the rock.
vitrophyre	Any porphyritic igneous rock with a glassy groundmass.
volcanic glass	Natural glass produced by the cooling of molten lava or some liquid fraction of molten lava too rapidly to permit crystallization.
volcanism	The processes by which magma and its associated gases rise into the crust and are extruded onto the earth's surface and into the atmosphere.
voucher collection	A collection of dried plant specimens usually mounted and systematically arranged for reference; a piece of supporting evidence.
vug	A cavity, often within a mineral lining of different composition from that of the surrounding rock.
waste	As used in this document, high-level radioactive waste or spent fuel.
waste canister	See "canister."
waste container	See "container."
waste form	The radioactive waste materials and any encapsulating or stabilizing matrix.
waste management	The planning, execution, and surveillance of essential functions related to the control of radioactive (and nonradioactive) waste, including treatment, solidification, packaging, transportation, initial or long-term storage, surveillance, disposal, and isolation.

waste matrix	The material that surrounds and contains the waste and to some extent protects it from being released into the surrounding rock and ground water. Only material within the canister (or drum or box) that contains the waste is considered part of the waste matrix.
waste package	The waste form and any containers, shielding, packing, and other sorbent materials immediately surrounding an individual waste container.
water budget	The quantification of the amount of water entering, moving through, and leaving a flow system; sometimes called "water balance."
water flux	A stream of flowing water; flood or outflow of water.
watershed	A drainage basin.
water table	The water surface in a body of ground water at which the water pressure is atmospheric.
welded tuff	Indurated volcanic ash in which the constituent glassy shards and other fragments have become welded together, apparently while still hot and plastic after deposition. Where the distinction between nonwelded and partly welded tuff is necessary, the boundary should be placed at or close to that point where the deformation of glassy fragments becomes visible. The transition from partly to densely welded tuff is one of progressive loss of pore space accompanied by an increase in the deformation of the shards and pumiceous fragments.
wind rose	A diagram showing the distribution with direction of the frequency and the speed of the wind.
Wisconsin	Pertaining to the last definitely ascertained glacial stage of the Pleistocene epoch in North America.
worst-case analysis	An analysis based on assumptions and input data selected to yield a "worst impact" statement.
x-ray diffraction analysis	Analysis of the crystal structure of materials by passing x-rays through them and registering the diffraction (scattering) image of rays.
xenolith	An inclusion in an igneous rock to which it is not genetically related.
Young's modulus	A modulus of elasticity in tension or compression, involving a change in length.

zeolites Any of various silicates analogous in composition to the feldspars and occurring as secondary minerals in cavities, along fractures, and on joint planes in basaltic lavas. Occur also as authigenic minerals in sedimentary rocks.

Zircaloy An alloy whose major constituent is zirconium, used as cladding material for nuclear fuel rods.

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ACRONYMS AND ABBREVIATIONS

ACOE	Army Corps of Engineers
Act	Nuclear Waste Policy Act of 1982
AEC	Atomic Energy Commission
AISI	American Iron and Steel Institute
ALARA	as low as is reasonably achievable
ANSI	American National Standards Institute
BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management (U.S. Department of the Interior)
BTU	British Thermal Unit
BWR	boiling water reactor
CBRS	Coastal Barrier Resources System
CDA	Copper Development Association
CFR	Code of Federal Regulations
CH-TRU	contact-handled transuranic waste
CHLW	commercial high-level waste
CRD	Comment Response Document
CSF	consolidated and overpacked spent fuel
CSIR	Council for Scientific and Industrial Research (S. African)
DAF	Department of the Air Force
dB	decibel
dBA	decibel (A-weighting network)
DHLW	defense high-level waste
DOA	U.S. Department of Agriculture

DOC	U.S. Department of Commerce
DOE	U.S. Department of Energy
DOE/NV	U.S. Department of Energy, Nevada Operations Office
DOI	U.S. Department of the Interior
DOT	U.S. Department of Transportation
DWPF	defense waste processing facility
E-MAD	Engine Maintenance, Assembly and Disassembly
EA	Environmental Assessment
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
ESD	Employment Security Department (State of Nevada)
ESF	exploratory shaft facility
FAA	Federal Aviation Authority
FASM	fuel-assembly structural material
FSAR	final safety analysis report
FWS	U.S. Fish and Wildlife Service
GETT	grants-equal-to-taxes
g	physical constant repr. the acceleration due to gravity
H-3	tritium
HAW	high-activity waste
HC	hydrocarbons
HEPA	high-efficiency particulate air
HLW	high-level waste
HMTA	Hazardous Materials Transportation Act

IAEA	International Atomic Energy Agency
ICC	Interstate Commerce Commission
KEV	thousands of electron volts
LET	linear energy transfer
LMFBR	liquid-metal fast breeder reactor
LWR	light water reactor
M	magnitude
MOA	Memorandum of Agreement
MPC	maximum permissible concentration
MRS	monitored retrievable storage
MTHM	metric tons of heavy metal
MTU	metric tons of uranium
NAAQS	Nevada Ambient Air Quality Standard
NAC	Nevada Administrative Code
NAFR	Nellis Air Force Range
NAS	National Academy of Sciences
NCRP	National Council on Radiation Protection and Measurements
NDCNR	Nevada Department of Conservation and Natural Resources
NDEP	Nevada Department of Environmental Protection
NDH	Nevada Department of Health
NDHPA	Nevada Division of Historic Preservation and Archaeology
NDOSH	Nevada Division of Occupational Safety and Health
NDSL	Nevada Division of State Lands
NDW	Nevada Department of Wildlife

NDWR	Nevada Division of Water Resources
NGI	Norges Geotekniske Institute (Norwegian Geotechnical Inst.)
NNWSI	Nevada Nuclear Waste Storage Investigations
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRC	U.S. Nuclear Regulatory Commission; National Research Council
NRDA	Nevada Research and Development Area
NRS	Nevada Revised Statutes
NSIM	Nevada State Inspector of Mines
NSR	New Source Review
NTS	Nevada Test Site
NTSO	Nevada Test Site Support Office
NWPA	Nuclear Waste Policy Act of 1982
NWSR	National Wild and Scenic River
NWTS	Nuclear Waste Terminal Storage
OCRWM	Office of Civilian Radioactive Waste Management
OCS	Office of Community Services (State of Nevada)
ONWI	Office of Nuclear Waste Isolation
PAC	potentially adverse condition
PLO	Public Land Order
PM	particulate matter
PMF	probable maximum flood
PNL	Pacific Northwest Laboratories
PPM	parts per million
PRCR	preliminary repository concepts report

PSD	Prevention of Significant Deterioration
PUREX	plutonium and uranium recovery through extraction
PWR	pressurized water reactor
Q	quality factor
RAD	See Glossary
RAT	radiological assistance team
REM	See Glossary
SA/V	ratio of Surface Area to Solution Volume
SARP	safety analysis report for packaging
SCP	Site Characterization Plan
SCS	Soil Conservation Service
SF	spent fuel
SHPO	Nevada State Historical Preservation Office
SIP	State Implementation Plan
SJC-WCD	San Juan County Water Conservation District
SMSA	standard metropolitan statistical area
SNGBZ	Sierra Nevada-Great Basin Boundary Zone
SPCC	Spill Prevention Control and Counter-measure Plan
SR	State Route
Supply System	Washington Public Power Supply System
SW	secondary waste
SWL	Static Water Level
TLD	thermoluminescent dosimeter
TRU	transuranic (waste)

TWC	Texas Water Commission
Tpt	Topopah Spring Member of the Paintbrush Tuff
t	a variable, representing a time interval
UNLV	University of Nevada, Las Vegas
UNR	University of Nevada, Reno
UP	Union Pacific Railroad
USAF	U.S. Air Force
USC	U.S. Code
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
USLE	universal soil-loss equation
UTF	underground test facility
UTM	Universal Transverse Mercator
UZ	unsaturated zone
VRM	visual resource management
VSP	vertical seismic profiling
WHB	waste handling building
WHPF	waste handling and packaging facility
WIPP	Waste Isolation Pilot Plant
WLM	working level month
WNP	Washington Public Power Supply System Nuclear Project
WPPSS	Washington Public Power Supply System
WSA	Wilderness Study Area
WVHLW	West Valley high-level waste

TRANSPORTATION

Appendix A

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Appendix A

TRANSPORTATION

A.1 INTRODUCTION

This appendix, which is common to all environmental assessments, presents general background information on transportation topics and issues and provides supplementary references to more-detailed sources of information. The discussions throughout the appendix are specific to the spent-fuel and high-level-waste shipments that will be made to a repository.* The agencies responsible for the regulation of radioactive-material transportation are identified, and their regulations or requirements are reviewed. The shipping casks and cask concepts that will be developed in compliance with the regulatory framework are also described. These topics are discussed in the context of protecting public health and safety against the potential hazards associated with normal transportation, accidents, and sabotage. In addition, the bases for, and the methods of, evaluating the relative transportation risk and cost for each of the sites nominated as suitable for characterization are briefly considered. Separate sections are included to consider the use of barges as an alternative mode of transportation, and to discuss how the consideration of a second repository would affect the results of a single-repository analysis. Also included is a section that describes the criteria developed to aid in the application of the siting guideline on transportation. Finally, several of the major transportation issues (routing, prenotification, emergency response, and liability) that have been raised by the public are discussed.

For purposes of discussion in this appendix, the following terms unique to the vocabulary of transportation are defined:

- Packaging (cask) - the assembly of components, excluding contents, that shields and contains the radioactive contents. Packaging may consist of one or more receptacles, absorbent materials, spacing structures, thermal insulation, radiation shielding, and devices for cooling or absorbing mechanical shocks.
- Package - packaging together with its contents as presented for transportation. This term is distinct from "waste package," which denotes the contents of the waste-emplacement hole in the repository.
- Normal transportation - all conditions of transportation except those that result from accidents and sabotage.

Additional lists of transportation terms that may be of interest are found in 49 CFR 171.8, 49 CFR 173.403, and 10 CFR 71.4.

* For convenience and brevity, the term "radioactive waste" or simply "waste" is often used to mean spent fuel or all of the waste to be accepted by the repository.

A.2 AGENCIES WITH JURISDICTION OVER THE TRANSPORTATION OF RADIOACTIVE WASTE

A.2.1 FEDERAL JURISDICTION

The number of Federal organizations involved in the regulation of radioactive-waste transport is large, and their responsibilities and authorities are interrelated. However, only the functions of the U.S. Department of Transportation (DOT), the U.S. Nuclear Regulatory Commission (NRC), and the U.S. Department of Energy (DOE) are discussed here because of their predominance in radioactive-materials transport. More-detailed information and information about organizations not mentioned can be found in reports by Wolff (1984) and the NRC (1977).

The DOT has regulatory responsibility for safety in the transportation of all hazardous materials, including radioactive materials. This responsibility extends to all modes of transportation that would be considered for shipping waste to the repository. Under its establishing legislation, the Department of Transportation Act of 1966, the DOT is responsible for encouraging cooperation among Federal, State, and local governments, carriers, shippers, labor, and other interested parties to achieve national transportation objectives. The regulatory and enforcement authority of the DOT over the shipments of radioactive material that are in, or may affect, interstate commerce was extended by the Hazardous Materials Transportation Act (HMTA) of 1974 to include, but not be limited to, the packaging of specified types and quantities of radioactive materials, handling, labeling, placarding, routing, and driver training.

The NRC provides supplementary regulations related to the transportation of radioactive material. Under the Atomic Energy Act of 1954, as amended, the NRC has responsibility for safety in the possession, use, and transfer (including transportation) of by-product, source, and special nuclear materials. The NRC licenses commercial entities that possess and use these materials. It also promulgates regulations applicable to NRC-licensees regarding the packagings of specified quantities of highly radioactive materials, prenotification of shipments, and the physical protection of spent-fuel shipments from acts of theft and sabotage. The DOT, by agreement with the NRC, accepts the NRC standards of 10 CFR Part 71 for packagings. This agreement has been formalized in a memorandum of understanding between the two agencies (Federal Register, Vol. 44, p. 38690, July 2, 1979). These standards are now in general agreement with international regulations. To aid in enforcement, the NRC requires its licensees to comply with DOT regulations when those entities are not otherwise subject to the DOT regulations.

The shipments of radioactive material conducted by the DOE are also subject to DOT regulations. Authority has been granted to the DOE by DOT regulations (49 CFR 173.7) to approve and certify packagings made by or under the direction of the DOE, as long as the evaluation, approval, and certification are against packaging standards equivalent to those specified in the NRC regulations in 10 CFR Part 71. Although the DOE will take title to all shipments of spent fuel and will be the shipper of record with the authority to use DOE-certified packages, a procedural agreement (Federal Register, Vol. 48, p. 51875, November 14, 1983) has been signed between the

NRC and the DOE; it provides that the DOE will, while making radioactive-waste shipments from NRC-licensed facilities to facilities established under the Nuclear Waste Policy Act (the Act), use NRC-certified packages. The agreement is currently limited to matters of health and safety incident to packaging.

The Act also restates the requirement that the DOE must comply with DOT regulations. A memorandum of understanding between the DOE and the DOT delineates the respective responsibilities and establishes common planning assumptions that the DOE and the DOT will observe in the implementation of transportation requirements under the Act (Federal Register, Vol. 40, p. 47421, November 18, 1985).

A.2.2 ROLE OF STATES

The States also have an important role in regulating the transportation of radioactive materials. Some States have adopted DOT regulations and apply them to intrastate shipments as well as interstate shipments. A particularly important role of the State under DOT regulations is that of designating preferred highway routes for shipments of the type of radioactive materials that would be shipped under the Act (DOT, 1984). A more complete discussion of the States' roles in highway routing is presented in Section A.13.3.1.

A.3 PARTICIPANTS IN THE SHIPPING PROCESS

Three major participants in the shipping process are subject to existing Federal regulations: the shipper, the carrier, and the receiver. The shipper is responsible for the transfer of the radioactive material even though the material may be physically transported by someone else. The shipper must identify the contents of the package, inform the carrier (the actual transporter) of the contents of the package, and must notify the States through which a shipment will pass. Also, the shipper must perform contamination and radiation-level surveys, prepare shipping papers, and certify on the shipping papers that the package is properly prepared. The shipper is instrumental in ensuring the safety of the shipment. The carrier must placard the vehicle, provide any training that may be required, prepare a route plan, and ensure that prescribed routes are followed. The receiver generally acts to support the shipper by inspecting shipments on arrival and by preparing the transportation vehicle for the return trip, ensuring that contamination levels, if any, are below regulatory limits.

The shipping participants under the Act are expected to be the DOE as the shipper of record (the responsibility of separate offices within the DOE for shipments of defense waste to a repository has not been decided upon yet), commercial transporters as the carriers, and the DOE's Office of Civilian Radioactive Waste Management (OCRWM) as the receiver.

A.4 REGULATIONS RELATED TO NORMAL TRANSPORTATION

The hazards of radioactive-material transportation under normal conditions are minimized by existing regulations. All radioactive materials emit penetrating radiation of varying strength and penetrating power, and shielding is provided in the packaging to reduce this radiation to low levels. Many administrative regulations have been developed to (1) identify packages that contain radioactive material and (2) limit exposures to low levels.

A package must be properly prepared and have proper markings and labels. In addition, a vehicle carrying radioactive material of the type that would be shipped to a repository must be placarded for further identification. A tamper seal is used to show that a shipment has not been opened by unauthorized personnel. Furthermore, the shipper must prepare shipping papers and driver instructions that identify the materials being transported and provide appropriate instructions for shipping.

Limits are prescribed for both temperature and radiation-dose rates. The accessible surface temperatures of packages may not exceed 82°C (180°F). Most likely, the casks for the DOE's waste-management program will be designed to ensure that the radiation-dose rates for shipments to a repository will be at the regulatory limit of 10 mrem/hr at 2 meters (6.6 feet) from the external surface of the vehicle or trailer. A radiation dose equivalent to 1 year's exposure to natural background radiation would be received in 10 to 15 hours if a person were to stand at the 2-meter (6.6-foot) distance. Although these exposures are low, the labels and placards are intended to alert the public and to prevent prolonged inadvertent contact with a shipping vehicle or package.

Since loose radioactive material may adhere to the external surface of the package or the vehicle, external contamination is also monitored to ensure that it does not reach harmful levels.

There are many other regulations that have an important effect on the safety and efficiency of radioactive-material shipments. These regulations include requirements for driver training and qualification, notifications, and safeguards. A good review of current DOT regulations can be found in a recent DOT report (DOT, 1983b). The regulations are found in 49 CFR Parts 100-179. NRC regulations are found in 10 CFR Part 71 and Part 73.

A.5 REGULATIONS RELATED TO MITIGATING THE CONSEQUENCES OF ACCIDENTS

During the period from 1971 to 1981, over 1,500 truck and rail shipments of spent fuel were completed (Newman, 1985), and only 4 accidents occurred (Emerson and McClure, 1983). Two of these accidents occurred when the casks were empty. None of the casks released radioactive material.

The packaging is the primary means of protection in the event of an accident. The stringency of regulations for packaging is related to the hazard of the radioactive contents if they were to be dispersed during an accident. For the radioactive materials that will be shipped to a repository,

packagings must be designed to preclude significant releases even under severe accident conditions. Under the conditions of the vast majority of accidents, packaging design will preclude entirely the release of material. This section discusses design criteria in regulations, while Section A.7 discusses proposed designs of packagings for shipments to a repository.

Among other requirements, packagings for shipments to a repository will have to survive the testing conditions identified in 10 CFR Part 71. These testing conditions have been estimated to be more severe than those encountered in at least 99.9 percent of all transportation accidents (McClure, 1981). By demonstrating the capability to survive such severe conditions, a packaging can be expected to completely contain its contents during an accident, and this has been the experience to date.

The specific tests to which the same packaging is subjected are as follows:

1. A free drop of 9 meters (30 feet) onto an unyielding target.
2. A free drop of 1 meter (40 inches) onto a puncture probe of a specified size.
3. An exposure to an engulfing thermal environment of 800°C (1,475°F) for 30 minutes.
4. An immersion under 0.9 meter (3 feet) of water for 8 hours.
5. An immersion under 15 meters (50 feet) of water for 8 hours (an undamaged packaging may be used for this test).

Information about the basis for these specific tests can be found in a report published by the International Atomic Energy Agency (IAEA, 1973).

In the first four tests, the same package must be tested in sequence and in the orientation expected to cause the most damage. The extent to which a cask survives such a test is measured by prescribed allowable leak rates and prescribed maximum exposure rates at specified distances from the surface of the package. Regulations, detailed descriptions, leak rates, and survival criteria can be found in 10 CFR 71.51(a)(2), in DOE Order 5480.1, in an NRC regulatory guide (NRC, 1975), and in a standard issued by the American National Standards Institute (ANSI, 1977).

Once a package design to be used for shipments to a repository (not all radioactive-material packages must survive accident conditions) has been demonstrated to survive the rigorous accident conditions as well as many other criteria, a certificate of compliance is issued. The certificate specifies the operating conditions under which the package may be used.

Both the regulations and the certificates can be modified to include experience that relates to the performance of packages. For example, in a recent occurrence (Klingensmith et al., 1980), damaged spent fuel became oxidized during shipment, and a serious contamination problem resulted during unloading. As a result, the NRC has modified the certificates of compliance

of currently certified spent-fuel casks to require that they be operated with inert atmospheres in the cask cavity. By using an inert gas in the cask cavity, the potential for fuel oxidation is substantially reduced.

Since the transportation packaging can be relied on for protecting the public during an accident, shipments can be allowed to occur in general commerce. Consequently, relatively few Federal regulations for vehicles are imposed on the carriers of radioactive materials (excluding physical protection requirements) beyond those required for the carrier of any hazardous material. Vehicle-safety conditions are addressed by other Federal and State regulations that are not specific to vehicles carrying radioactive material. For example, truck safety is governed by the Bureau of Motor Carrier Safety (49 CFR Parts 390-398), which imposes vehicle-safety and driver standards on all interstate truck carriers. Along with other functions, the Bureau conducts unannounced roadside inspections of truck carriers and drivers. During an inspection, the weight and a variety of safety considerations, including vehicle lights and brakes and driver documents, are checked. For rail shipments, similar inspection criteria and safety requirements have been promulgated by the Federal Railroad Administration in 49 CFR Parts 209-236. Regulations related to hazardous materials transportation by rail are discussed in Section A.13.4.2.

A.6 REGULATIONS RELATED TO SAFEGUARDS

An issue that has caused concern about the public risk due to radioactive-material transportation is the hazard posed by the sabotage of a radioactive-material shipment. One postulated scenario is the destruction of a loaded cask with well-placed explosives. Such an attack would be of particular concern if it were conducted in a densely populated area.

A.6.1 SAFEGUARDS

In June 1979, the NRC published regulations for the protection of commercial-spent-fuel shipments. In 1980, after reviewing public comments and assessing its own experience in administering these regulations, the NRC published amendments to the rule. The NRC further amended the rule in 1982 to include State prenotification requirements. The amended rule is currently in effect as 10 CFR 73.37(a)-(f). These regulations were promulgated to address the issue of safeguarding spent-fuel shipments against acts of terrorism and sabotage, including the possible hijacking and subsequent sabotage of such shipments. Known as physical protection or "safeguard" regulations, these security rules are distinguished from other regulations published by the NRC and other Federal agencies that deal with issues of safety affecting the environment and public health. The safeguard regulations reflected analyses conducted in the mid 1970s. In particular, an NRC-sponsored study (DuCharme et al., 1978) suggested that the sabotage of spent-fuel shipments had the potential for producing serious radiological consequences in areas of high population density. The NRC concluded that to protect public health and to minimize danger to life and property, it was prudent to require that certain safeguard measures be taken to protect spent-fuel shipments until a more

precise and scientific analysis could be performed. The study had been concerned with areas of high population density, but, because of the possibility that shipments could be hijacked in low-population areas and subsequently transported to high-population areas, the requirements applied to all shipments regardless of routing.

The NRC stated in the preamble to the rule change that it had intended the original safeguard rules to be in effect until the results of confirmatory research became available and could be analyzed. The NRC and the DOE responded to this need for more testing by sponsoring separate but coordinated experimental programs. Both programs were designed to yield information about the release of radioactive material from a specified reference sabotage event that was defined in terms of the expertise of the saboteurs, the amount of explosives used, the type of charge employed, and the characteristics of the cask. The NRC-sponsored experiments (Schmidt et al., 1982) used model (small-scale) explosives against simulated casks containing irradiated fuel. The program sponsored by the DOE (Sandoval et al., 1983) included one full-scale and several small-scale experiments.

The results of both of these latter studies showed that the likely release of respirable radioactive particles from sabotage and the resulting consequences of individuals breathing such particles are substantially smaller than the estimates made in the previous NRC-sponsored study that had prompted issuance of the original safeguard regulations. That study had predicted several tens of early fatalities and hundreds of latent-cancer fatalities from sabotage in a densely populated urban area of a truck cask containing three fuel assemblies. The subsequent DOE and NRC-sponsored research predicted no early fatalities and fewer than 15 latent-cancer fatalities for the sabotage of a three-assembly cask in a similarly populated area. These latter consequences would occur only under assumptions that are very favorable to the saboteur. Assumptions concerning the age of the spent fuel (i.e., the cooling period), population density, and the lifetime of respirable particles were all postulated at worst- or near-worst-case levels. When such assumptions are changed to more closely resemble typical or normal transportation situations, the resulting consequences are predicted to decline further.

In June 1984, the NRC published proposed amendments to its existing safeguard regulations and solicited public comment. These amendments take into account the results of the experiments sponsored by the NRC and the DOE, but continue to provide for protection against the loss of control over a shipment and the unhindered movement of the shipment by a saboteur. The objectives of both the current rule and the proposed amendments are to--

1. Deny an adversary easy access to shipment-location information.
2. Provide for early detection of hostile moves against, or the loss of control over, a shipment.
3. Provide a means to quickly summon assistance from local law-enforcement authorities.
4. Provide a means to impede the unauthorized movement of a truck shipment into a heavily populated area.

The current NRC safeguard rule requires--

1. Advance notification of each shipment to the NRC.
2. Maintenance of a communications center to continuously monitor the progress of each shipment.
3. Keeping a written log describing the shipment and significant events during the shipment.
4. Advance arrangements with local law-enforcement agencies along the route.
5. Advance route approval by the NRC.
6. Avoiding scheduled intermediate stops to the extent practicable.
7. At least one escort to maintain visual surveillance of the shipment during stops.
8. Shipment escorts to contact the communications center every 2 hours to report the status of the shipment.
9. Capability to immobilize the cab or cargo-carrying portion of a shipment transported by truck.
10. Armed escorts in heavily populated areas.
11. On-board communications equipment.
12. Advance notification to the governor of a State (or the governor's designee) of a shipment to be transported within or through his State, giving the estimated date and time of entry into the State and applicable routing information. This information must not be publicly released until 10 days after the shipment has entered or originated within the State.

All of these requirements will continue to be in effect for shipments of spent nuclear fuel that has been cooled less than 150 days because there is currently not enough information on the consequences of sabotage to this "hotter" fuel to warrant regulatory modifications.

The proposed amendments change the regulations for shipments of spent fuel cooled 150 days or more by eliminating the requirements for--

1. Maintenance of a communications center.
2. Written logs.
3. Advance arrangement with local law-enforcement agencies.
4. Contacts every 2 hours by escorts.
5. Armed escorts in cities.
6. Advance route approval by the NRC.

At present, NRC's safeguard rules apply only to NRC licensees. However, DOT regulations require that DOE-owned spent fuel be shipped under a physical-protection plan that is equivalent to NRC safeguard rules and has been approved by DOT (49 CFR 173.22(c)). DOE Order 1540.1, which covers DOE transportation regulations, is being revised and will include physical protection procedures that essentially parallel the physical-protection procedures proposed by the NRC in 1984.

When shipping commercial waste to a repository, the OCRWM will comply with whatever NRC shipment-protection requirements are in force at the time. The NRC safeguard requirements at present are limited to spent-fuel shipments. The OCRWM will work with the NRC to establish the need for, and the function of, safeguard requirements for the other radioactive waste that could be shipped under the Act.

A.6.2 CONCLUSION

Though transportation packagings have not been specifically designed to mitigate the consequences of a sabotage event, they have been shown experimentally to limit to low levels the potential adverse health consequences to the public. Predictions based on releases experimentally determined in both DOE and NRC studies indicate that no immediate radiation-induced deaths and a small number of latent-cancer fatalities would be expected even in a very densely populated area (Sandoval et al., 1983). To create the level of hazard encountered in the experiments, such sabotage attempts would have to be performed by trained experts, and precise placement of the explosives in the most vulnerable positions would be necessary.

In order to protect the health and safety of the public, the packaging of shipments made to a repository will be as strong as those used in the experimental studies.

A.7 PACKAGINGS

This section discusses the design and fabrication of transportation packagings, trends in future designs, the designs assumed for the cost and risk analysis, and possible future developments.

A.7.1 PACKAGING DESIGN, TESTING, AND ANALYSIS

Radioactive-material packagings, or casks, are designed and certified to carry specific contents. This is necessary because of the unique thermal, radiological, and criticality characteristics of the contents. Other materials can be carried in the cask only if it can be shown that they present no greater radiological, thermal, or criticality hazards than those of the certified contents. Several cask types will be used for transporting waste to a repository. Generally, the size of the package will be dictated by the mode of transportation.

The type of packaging to be used for shipments to a repository is required to survive the conditions of both normal transportation and accidents. Survival is determined by the extent to which the packaging contains its contents, shields against excessive levels of radiation, and prevents a nuclear chain reaction from occurring even after being subjected to the prescribed hypothetical accident conditions (see Section A.5).

A new packaging is designed through a rigorous process similar to that for other nuclear-related products. If a feasible design is proposed, the design proceeds through an engineering analysis of its survivability when subjected to the testing conditions. Physical engineering tests may be conducted during this stage to support analyses. Proof of survivability under accident conditions is required either through analysis, full-scale or model testing, or a combination of both. Once feasibility and survivability are ensured, a final design is prepared. In the design of packaging used for commercial-waste shipments to a repository, all of this effort will be performed by the cask designer for the DOE under a rigorous quality-assurance program. Once the DOE is certain that the design satisfies all requirements, a safety-analysis report for packaging (SARP) will be submitted to the NRC. This SARP will contain a description of all analyses and will be the means for transmitting all operational and safety information to the reviewer. Once the NRC is convinced that all criteria have been satisfied, it will issue a certificate of compliance.

Since packaging certification can be based on engineering analysis, without actual physical testing, it is important to have confidence that the analytical results closely represent those that might be expected to occur if a package were actually subjected to accident conditions. Several experimental programs, both reduced-scale and full-scale, have been run to produce carefully controlled accident environments that can be directly correlated with analysis (Jefferson and Yoshimura, 1978). The correlations have been reasonably close, and much confidence has been developed in analytical modeling capabilities as a reliable and cost-effective tool to replicate response to accident conditions.

A.7.2 TYPES OF PACKAGING

The analyses presented for transportation in this environmental assessment are based on the representative characteristics of a new family of casks that are expected to be used to transport spent fuel and high-level waste. These casks either are being designed now or will be designed in the future, and more accurately represent the type of packaging that will be used than do existing casks being used to transport commercial spent fuel.

As stated earlier, packagings are designed for specific contents; spent-fuel casks are no exception. The existing casks that are currently in use are designed to shield, dissipate heat, and prevent a nuclear chain reaction in spent fuel that has just come out of a reactor. Because the spent fuel to be shipped to a repository will have been out of the reactor for many years (5 years at a minimum), the existing casks are "overdesigned" for the mission. Although the expected radiation-dose rates would be much lower than those allowed by regulation, the cask payloads are also lower than optimum, thus requiring more shipments. The lower radiological risk per shipment using

existing casks would be roughly offset by the increased overall risk that would result from the increased number of required shipments.

The DOE is planning new cask designs that will increase payloads and substantially reduce the number of shipments. Table A-1 presents the cask capacities assumed for performing the consequence and risk analyses in Section A.8. These casks will benefit from past designs, but the application of current technology and analytical tools may allow improvements in design. For example, new-generation casks will probably be designed to be handled entirely remotely and thus will eliminate much routine worker exposure.

A.7.2.1 Spent-fuel casks

Figures A-1 and A-2 show a representative truck cask and a representative rail cask that will be used to transport spent fuel to a repository or to a facility for monitored retrievable storage (MRS) if such a facility is approved by Congress (see Section A.8.3.4). The 100-ton rail cask depicted could also be used for barge transport. The truck cask will be able to accommodate two spent-fuel assemblies from a pressurized-water reactor (PWR) or five assemblies from a boiling-water reactor (BWR). This represents about a doubling of capacity over existing truck casks. The representative truck cask will weigh 21,773 kilograms (48,000 pounds) when empty; when the cask is loaded on the tractor and trailer, the vehicle will weigh less than 36,288 kilograms (80,000 pounds), a weight that will allow it to travel relatively unimpeded by State weight limits for vehicles on the nation's highways. The cask may be constructed of carbon or stainless steel; shielding may be provided by steel, depleted uranium, or lead.

The rail/barge cask will be able to accommodate 14 PWR or 36 BWR assemblies, again representing a doubling of current cask capacity. The concept shown has a stainless-steel body with a sufficient wall thickness to meet all structural and radiation-limit requirements of regulations.

The conceptual designs for both the truck and the rail/barge casks have external impact limiters (shock absorbers designed to reduce the effects of accidents) mounted on the casks, as well as internal impact limiters made of crushable honeycomb material.

A.7.2.2 Casks for defense and commercial high-level waste

An artist's concept of the truck cask for defense high-level waste (DLHW) is shown in Figure A-3. It will be able to carry one 0.6- by 3-meter (2- by 10-foot) canister of vitrified defense waste (and possibly commercial high-level waste from the West Valley Demonstration Project (WVHLW)). When the cask is loaded on the tractor and trailer, the loaded trailer and tractor will weigh less than 36,288 kilograms (80,000 pounds). The cask will be constructed of stainless steel and will have a shielding sleeve of depleted uranium and steel. The cask will have features that allow it to be remotely handled, and the impact limiters will not have to be removed during loading

Table A-1. Reference cask capacities

Origin and destination	Waste type ^a	Container	Capacity ^b
SPENT FUEL AND SECONDARY WASTE			
From reactors to repository or MRS facility			
Truck	Spent fuel	Unconsolidated assemblies	2/5
Rail	Spent fuel	Unconsolidated assemblies	14/36
From MRS facility to repository, 100-ton casks			
Salt sites	Spent fuel	Disposal container ^c	24/30
Tuff site	Spent fuel	Disposal container ^c	18/42
Basalt site	Spent fuel	Disposal container ^c	24/45
From MRS facility to repository, 150-ton casks			
Salt sites	Spent fuel	Canister ^d	72/150
Tuff site	Spent fuel	Canister ^d	48/98
Basalt site	Spent fuel	Canister ^d	84/171
From MRS facility to all sites			
100-ton casks	Hardware and high-activity low-level waste	Canister ^e	4
150-ton casks	Hardware and high-activity low-level waste	Canister ^e	7
Rail	Contact-handled transuranic waste	Drum	(f)
HIGH-LEVEL WASTE			
Defense waste			
Truck	Glass HLW	Canister	1
Rail	Glass HLW	Canister	5
Commercial waste ^g			
Truck	Glass HLW	Canister	1
Rail	Glass HLW	Canister	7

^a PWR = pressurized-water reactor; BWR = boiling-water reactor.

^b Pairs of numbers show the number of PWR and BWR assemblies, respectively; for example, 2/5 means 2 PWR assemblies or 5 BWR assemblies.

^c Disposal containers suitable for direct emplacement in a repository. Container sizes are different for each repository host rock.

^d In thin-wall canisters that would require encapsulation in disposal container at the repository. Canister sizes are different for each repository host rock.

^e A canister contains five 55-gallon drums.

^f Thirty-six drums per transport package, two packages per railcar.

^g High-level waste from the West Valley Demonstration Project.

Figure A-1. Truck spent fuel cask.

Figure A-2. Rail/barge spent fuel cask.

Figure A-3. DHLW truck cask.

and unloading. A rail cask may also be developed; and its capacity is expected to be five canisters of vitrified defense high-level waste (see Table A-1.)

A.7.2.3 Casks for use from an MRS facility to the repository

The DOE's Mission Plan (DOE, 1985) discusses an improved-performance waste-management system that includes a facility for monitored retrievable storage (MRS). Fully integrated into the system, the MRS facility would perform most of the waste-preparation functions now assigned to the repository. In particular, it would consolidate the spent-fuel rods, which are contained in rectangular spent-fuel assemblies, into a tighter circular array, load the consolidated rods into a metal canister, and store the canister until shipment to a repository, where the canisters would be encapsulated in disposal containers and emplaced in the underground disposal rooms. It would also be possible to have the MRS load the consolidated-fuel canisters into disposal containers, which would require no further preparation at the repository.

Casks that would be used in transporting the consolidated spent fuel from the MRS facility to the repository have not yet been designed; however, any design would be certified by the NRC. Scoping analyses have been completed and allow projections of cask capacities to be made. These projections are presented in Table A-1 for casks that weigh 100 and 150 tons. The larger cask may be feasible if an MRS facility is approved by Congress. The cask capacities depend on the host rock of the repository because each host rock is assumed to require a unique canister design and size.

The consolidation of spent-fuel rods at an MRS facility would separate the fuel from the structural components and therefore create another waste type that requires disposal. This secondary waste is separated into three classes: hardware, high-activity low-level waste (HAW), and contact-handled transuranic waste (CH-TRU). It is assumed that the hardware and high-activity waste would be loaded into 55-gallon drums, with five drums loaded into a canister. Packaging capacities for these wastes are given in Table A-1. The transuranic waste would be loaded into 55-gallon drums and shipped in a packaging that is assumed to have a capacity of 36 drums. Two of these packages could be carried by a railcar while only one could be carried by a truck trailer.

A.7.3 POSSIBLE FUTURE DEVELOPMENTS

A.7.3.1 Mode-specific regulations

Even with the safety record of packagings that have been analyzed or tested to survive accident conditions, the NRC is currently reviewing regulations defining accident test conditions in order to assess whether the conditions sufficiently bound those experienced in real accidents. The regulations prescribing accident conditions for transportation are not specific to the mode of transportation, the implicit assumption being that the conditions for all modes are covered by the current standards. Such an

assumption has been questioned, and, in response, the NRC is comparing the current standards with actual accident experience for all modes.

A.7.3.2 Overweight truck casks

Highway load restrictions limit the weight of truck casks, which in turn limits cask payloads. In general, these limitations are intended to protect the nation's highway system from damage. Considering the safety objective of minimizing the number of spent-fuel shipments, however, the DOE, in approving designs for future casks, will balance the benefit of reducing shipments against possible road damage caused by overweight vehicles.

Slightly larger truck casks can increase payload capacity, which, in turn, can significantly reduce the number of shipments. The DOE intends to investigate the potential of these larger casks and will consider their use if additional road damage can be minimized. The proposed use of any overweight equipment will be subject to early review and comment by appropriate State officials because the DOE recognizes the State as the permit-issuing authority for shipments requiring overweight or oversize equipment over the nation's highway system.

A.7.3.3 Rod consolidation

Another way to increase the capacities of spent-fuel casks is to consolidate spent-fuel rods in a canister, as mentioned above for the MRS facility. By so doing, cask capacities might be doubled. Preliminary investigations indicate that, in terms of cask design, the principal problems associated with rod consolidation are the increase in weight and the amount of heat that must be dissipated.

A.7.3.4 Advanced handling concepts

Since the number of radioactive-material packages received and handled at a repository will be high, even the low levels of radiation at the surfaces of the packages would be sufficient to cause high total worker exposure. In an attempt to minimize worker exposure, the use of advanced remote-handling equipment, such as robotics, for unloading the packages is being investigated. New shipping casks will be designed to facilitate the cask handling and unloading operations at the repository or MRS facility.

A.7.4 CONCLUSIONS

The design and performance of current packagings are adequate for the specific contents for which they were designed. However, the waste to be transported to a repository would not be efficiently transported in existing casks since it is older and cooler than the contents for which the existing casks were designed (typically spent fuel cooled for 180 days). Therefore, new casks designed for fuel at least 5 years old will be added to the fleet.

These casks will have increased capacities and features that facilitate remote handling. Because these new casks more realistically represent future shipping operations, the expected characteristics of these casks are used in this environmental assessment.

A.8 POTENTIAL HAZARDS OF TRANSPORTATION

This section provides a numerical estimate of the hazard associated with transporting radioactive waste to a repository. In response to numerous comments received on the draft Appendix A, additional emphasis was placed on the potential consequences to an individual, as opposed to a general population. The goal was to answer the frequent question: "What happens to me, if ...?" After explaining the consequences that could be experienced by an individual affected to a credible maximum extent, the consequences are extrapolated to a general population and then finally are combined with accident probabilities to produce an expected value of risk to the public. A separate analysis was performed to consider barge transport, which currently is thought only to provide a potential supplementary role in the transportation system (see to Section A.10). The potential uncertainties inherent in the results presented here are also discussed.

It must be emphasized at this juncture that all analyses are thought to be conservative, and hence the risks they predict are expected to be much greater than the risk that may actually occur.

A.8.1 POTENTIAL CONSEQUENCES TO AN INDIVIDUAL EXPOSED TO THE MAXIMUM EXTENT

The analyses in this section are really ("snapshots in time") where an individual is exposed as a result of a particular set of circumstances that may never happen and would probably never happen twice in exactly the same way or to the same individual. These analyses are specific to a single shipment, and details about shipping schedules and scenarios are deferred until Section A.8.2.

A.8.1.1 Normal transportation

This section presents estimates of credible maximum radiation doses that may be received by a person from selected activities that could result from transportation operations. The activities are not related to accidents but rather could occur during normal operations.

The results in the tables are taken from Sandquist et al. (1985). Sandquist et. al. represent truck and rail casks with a simple analytical model and assume that the dose rates emitted from the casks are at regulatory levels (i.e., at the maximum levels permitted by existing regulations). Table A-2 presents estimates for a truck cask, and Table A-3 is for a rail cask. A number of services or activities are analyzed for each mode.

In order to explain what the results in the tables mean, consider Table A-2 for truck. Under the "truck servicing" category, the table gives the dose

Table A-2. Projected maximum individual exposures from normal transport
(truck spent-fuel cask)^a

Description (service or activity)	Mean distance to center of cask (ft)	Maximum exposure time (min)	Dose rate and total dose
Caravan			
Passengers in vehicles traveling in adjacent lanes in the same direction as cask vehicle	35	30	0.04 mrem/min 1 mrem
Traffic obstruction			
Passengers in stopped vehicles in lanes adjacent to the cask vehicle; vehicles have stopped because of traffic obstruction	15	30	0.1 mrem/min 3 mrem
Residents and pedestrians			
Slow transit (because of traffic control through area with pedestrians)	20	6	0.07 mrem/min 0.4 mrem
Truck stop for driver's rest; exposures to residents and passers-by	130	^b	0.006 mrem/min 3 mrem
Slow transit through area with residents (homes, businesses, etc.)	50	6	0.02 mrem/min 0.1 mrem
Truck servicing			
Refueling (100-gallon capacity)			0.06 mrem/min
One nozzle from one pump	25 (at tank)	40	2 mrem
Two nozzles from one pump	25 (at tank)	20	1 mrem
Load inspection and enforcement	10 ^c	12	0.2 mrem/min 2 mrem
Tire change or repair of cask trailer	16 ^d	50	0.1 mrem/min 5 mrem
State weight scales	15	2	0.1 mrem/min 0.2 mrem

^a These exposures should not be multiplied by the expected number of shipments to a repository in an attempt to calculate a worst case because the same individual would not be exposed for every shipment, nor would these circumstances arise during every shipment. An individual residing 100 feet from a transportation route and witnessing every shipment would receive an annual dose of 2 to 8 mrem, depending on the mode of shipment and the cask size.

^b Assumed to be overnight (8 hours).

^c Inspection occurs near personnel barrier.

^d Changed tire is the inside tire nearest cask.

Table A-3. Projected maximum individual exposures from normal transport
(rail spent-fuel cask)^a

Description (service or activity)	Mean distance to center of cask (ft)	Maximum exposure time (min)	Dose rate and total dose
Caravan			
Passengers in rail cars or highway vehicles traveling in same direction and vicinity as cask vehicle	65	10	0.03 mrem/min 0.3 mrem
Traffic obstruction			
Persons in vicinity of cask vehicle stopped or slowed down by rail traffic obstruction	20	25	0.1 mrem/min 2 mrem
Residents and pedestrians			
Slow transit (through station or because of traffic control) through area with pedestrians	25	10	0.07 mrem/min 0.7 mrem
Slow transit through area with residents (homes, businesses, etc.)	70	10	0.02 mrem/min 0.2 mrem
Train stop for crew's personal needs (food, crew change, first aid, etc.)	150	120	0.005 mrem/min 0.7 mrem
Train servicing			
Engine refueling, car changes, train maintenance, etc.	35	120	0.04 mrem/min 5 mrem
Cask inspection and enforcement by train, State, or Federal officials	10	10	0.2 mrem/min 2 mrem
Cask-car coupler inspection or maintenance	30	20	0.07 mrem/min 1 mrem
Axle, wheel, or brake inspection, lubrication, or maintenance on cask car	25	30	0.09 mrem/min 3 mrem

^a These exposures should not be multiplied by the expected number of shipments to a repository in an attempt to calculate a worst case because the same individual would not be exposed for every shipment, nor would these circumstances arise during every shipment. An individual residing 100 feet from a transportation route and witnessing every shipment would receive an annual dose of 2 to 8 mrem, depending on the mode of shipment and the cask size.

delivered to a person changing a tire on the trailer of a truck carrying a loaded spent-fuel cask. To change the tire, that required him to be only 5 meters (16 feet) from the center of the cask. It was further assumed that changing the innermost tire (dual wheels) would take almost a full hour. The dose rate at the location was estimated to be 0.1 millirem (mrem) per minute, a rate that would produce a 5-mrem dose to an individual for the complete service procedure. This dose is about the same as that received on a transcontinental airplane trip. If this person were estimated to change many tires in a year, the DOE may impose administrative controls to minimize the accumulated dose. Such control could be something as simple as requiring temporary lead shields between the cask and the area where the tire was to be changed.

Many of the services or activities analyzed would require administrative controls if they were to happen routinely. Routine occurrences either would not be allowed, or administrative controls would be applied to limit cumulative exposures. These types of activities and services will be more fully analyzed during the preparation of the environmental impact statement. This analysis does highlight the fact that additional controls may be necessary for the large numbers of shipments that will occur under the Act, but it must also be emphasized that the simplified model used by Sandquist et al. (1985) will calculate doses much greater than expected.

A.8.1.2 Accidents

Table A-4 presents the results of an analysis performed by Sandquist et al. (1985) to evaluate the individual dose that may result from three classes of very severe accidents--accidents that would produce conditions more severe than the regulatory test conditions. Accidents of this severity are not likely to occur during shipments to a repository.

Each set of results in Table A-4 is for an accident in which there is a release from a rail cask carrying 14 PWR assemblies. The releases are consistent with those assumed in past analyses (Wilmot et al., 1983; Neuhauser et al., 1984) and are based on the release mechanisms defined by Wilmot (1981).

The three accident classes (4, 5, and 6) are taken from Wilmot et al. (1983). These are very severe accidents, all of which would produce conditions greatly exceeding those specified in the NRC regulations. A Class 4 accident would require a very severe impact (i.e., perhaps a 30-meter (100-foot) drop onto a granite slab). This impact would release adhered activation products and may rupture a few spent-fuel rods. A Class 5 accident requires a Class 4 impact with a subsequent very intense fire (a fire longer and hotter than that of the regulatory test). A Class 6 accident requires a Class 4 impact and an even hotter fire than Class 5. A Class 6 accident would result in the severe oxidation of ruptured fuel rods. These accidents are extremely unlikely; they are estimated to occur once in a million vehicle accidents.

The maximum dose received by an individual in the most severe accident is about 10,000 mrem; it would be incurred by a person standing about 70 meters (230 feet) from the scene of the accident. Most of the dose comes from

Table A-4. Estimated maximum individual radiation dose
for rail-cask accidents

Accident class ^c	Dose (mrem) ^{a, b}				Total
	Inhalation	Plume gamma	Ground gamma	Dust inhalation	
4	180	11	12	0.0001	200
5	6,100	71	91	0.004	6,300
6	9,000	550	710	0.0006	10,300

^a Maximum individual dose occurs about 70 meters (230 feet) downwind of the release point.

^b Values reported as the effective whole-body dose.

^c Accident class as defined by Wilmot et al. (1983). Class 6 is the most severe, but all classes have probabilities of less than 1 in a million accidents.

inhaling radionuclides from the plume. The dose itself would occur over decades and would come from radionuclides retained within the body. Even if all of the dose were received during a short ("acute exposure") period, the individual would show no symptoms nor have his life threatened. An "acute" dose of about 50,000 mrem would be required before any symptoms would be observable; a dose of more than 450,000 mrem would be required before the chance of dying within 30 days is 50-50 (NCRP, 1962).

The doses calculated can be greater or smaller, depending on the circumstances; however, the analyses made no attempt to account for the mitigating measures that would immediately be exercised after an accident. Even such simple measures as staying indoors could easily reduce the doses by tenfold or more. By carefully tracking the release of material as it is dispersed by the wind, such advisories can be made.

The dose received by a firefighter was calculated for an accident even if no radioactive material was released. If the firefighter spent an hour at the scene of the accident, he would receive a dose of up to 24 mrem. A description of this analysis is also given by Sandquist et al. (1985). If a firefighter was responding to an accident in which there was a release and did not use breathing protection, he could be expected to receive a dose of about 10,000 mrem, as described above for the maximumally exposed individual. With breathing protection, the dose could easily be reduced to less than 1,000 mrem.

A.8.2 CONSEQUENCES TO A LARGE POPULATION FROM VERY SEVERE TRANSPORTATION ACCIDENTS

In this section, some doses are calculated for a large population, not just for a single individual as in Section A.8.1. The accidents analyzed are very unlikely, on the order of 1 in a million accidents or less.

Two scenarios are postulated: (1) an accident where material is released during an accident, dispersed, and deposited on the ground and (2) an accident where the radionuclides released are deposited in a reservoir that is used for many purposes, including drinking water. The three most-severe accident classes defined by Wilmot et. al. (1983) are considered, as described in Section A.8.1.2. Three exposure pathways are considered: inhalation, cloudshine, and groundshine. A fourth, the inhalation of resuspended dust, was found to be unimportant in comparison with the other three. As shown in Table A-5, in the most-severe accident in an urban area, 22 latent-cancer fatalities are predicted for the ground-deposition case and 13 for the water-deposition case. These values are based on the assumption that no mitigating administrative control or accident-scene clean-up takes place. Evacuation would reduce these numbers, as would cleaning up the contaminated areas. In the water-deposition case, no credit was taken for the normal settling and filtering processes that take place during water treatment and would certainly be employed after an accident. Details can be found in the report by Sandquist et al. (1985).

Table A-5. Estimated 50-year population dose for rail-cask accidents^A

Accident consequence	Air release ^B								Water release in urban area ^E
	Urban area ^E				Rural area ^D				
	Inhalation	Plume gamma	Ground gamma	Total	Inhalation	Plume gamma	Ground gamma	Total	
CLASS 4 ACCIDENTS ^F									
Population dose (man-rem)	3	0.33	940	940	0.005	0.0005	1.4	1.4	180
Number of latent-cancer fatalities ^G				0.2				0.0003	0.04
CLASS 5 ACCIDENTS ^F									
Population dose (man-rem)	110	2.2	13,000	13,000	0.2	0.003	21	21	6,900
Number of latent-cancer fatalities ^G				3				0.004	1.4
CLASS 6 ACCIDENTS									
Population dose (man-rem)	150	17	110,000	110,000	0.2	0.03	170	170	63,000
Number of latent-cancer fatalities ^G				22				0.04	13

^A Estimates based on the assumption that there is no cleanup of deposited radionuclides.

^B The ground dose is the dose that would be received if each member of the population stayed at the same location for 50 years. The inhalation dose is a 50-year dose commitment from the inhalation of the passing plume. Doses are for the population within 80 kilometers (50 miles) of the release point.

^C Urban area assumed to have 10,000 people per square mile.

^D Rural area assumed to have 16 people per square mile.

^E Population dose from water ingestion. The noble gas krypton-85 is omitted because of its negligible uptake by a surface-water body. Population-dose estimates based on a 100-acre, 1-billion-gallon reservoir that supplies the domestic, agricultural, and industrial needs of 37 million people. No radioactive decay, settling, or filtration is assumed. The water-release accident is much less likely to occur than either of the air-release accidents.

^F Accident classes as defined by Wilmot et al. (1983).

^G Based on 1 man-rem = 2×10^{-4} latent-cancer fatality plus first- and second-generation genetic effects.

A.8.3 RISK ASSESSMENT

The preceding section presented the consequences of an accident to a large population. This section examines the expected risk to the public (as a group of individuals) by including not only the consequences but also the probability of the accident. The results depend on shipment logistics and schedules for all shipments. In order to describe the results more clearly and to explain the differences between the results presented in the draft appendix and in this final version, this section briefly describes the computational models and the revisions made in the models, the waste-management scenarios that were analyzed, and assumptions about the waste.

A.8.3.1 Outline of method for estimating population risks

By recognizing similarities and uniformities over a national or large regional scale, simplifying assumptions were made in the risk-assessment calculations. Such simplification is justified because the importance of the results presented is not so much in their absolute values but rather in their relative magnitude when compared among the potential repository sites.

The most important simplification was to create "unit-risk" factors, which represent the risk of transportation for a unit distance of travel in a defined population zone. The use and development of unit-risk factors have been described by Madsen et al. (1983).

Once the unit-risk factors have been obtained for the population zones required (in this analysis, three different population densities were considered), three other factors are needed to evaluate the total risk of transportation to a site: (1) the total distance per trip, (2) the fraction of travel in each of the population zones, and (3) the number of shipments that may occur. Actual distances for representative routes were calculated from each reactor and waste source to the potential repository sites. The number of shipments was calculated from detailed logistics models that are best described in the detailed text of Shay et al. (1985). How the fraction of travel in the various population zones was determined is discussed by Cashwell et al. (1985). It is sufficient here to mention that actual 1980 census data were reduced to population contours, which in turn were overlaid on postulated routes. The distance of travel in each zone was subsequently translated to a fraction of travel.

A.8.3.2 Computational models and methods for estimating population risks

The analytical tools (i.e., the analytical models or codes used in this analysis) have been extensively documented elsewhere, and the interested reader is encouraged to review this documentation for details of model development (AEC, 1972; NRC, 1977; Taylor and Daniel, 1977, 1982; Madsen et al., 1983; Wilmot et al., 1983; Neuhauser et al., 1984). This section identifies the models and shows that they have been developed, used, and verified sufficiently to establish their credibility.

The RADTRAN-II code, which was used to calculate the radiological unit-risk factors, is the product of about 10 years of development. Its precursor was used to produce the environmental assessment used in Interstate Commerce Commission (ICC) hearings concerning the issue of hauling radioactive material in trains dedicated to radioactive material (ICC, 1977). RADTRAN was used to produce documents that are current standards for evaluating the risk of transporting radioactive materials (NRC, 1977, 1983). Furthermore, the code has been used as the basis for other significant risk-assessment tools, including METRAN (Finley et al., 1980), which evaluates the risk of transportation in urban areas, and INTERTRAN (Ericson and Elert, 1983), which is the risk-assessment tool of the International Atomic Energy Agency.

The nonradiological unit-risk factors were calculated from available data collected from actual transportation records (Cashwell et al., 1985).

HIGHWAY (Joy et al., 1982) and INTERLINE (Peterson, 1984) are routing models for highway and rail shipment. Developed over the past several years, they are updated periodically to reflect current road and track conditions and railroad ownership. They are benchmarked against reported mileages and observations of commercial truck and rail firms.

A.8.3.3 Changes in the analytical models and methods for estimating population risks

Many significant improvements have been made in the analytical models and methods since the analyses were by completed by Neuhauser et al. (1984), for the draft environmental assessment. A couple of the modifications have resulted in significant changes in the absolute value of the expected results, and therefore it is important to identify them. The interested reader is encouraged to review the references given.

The most important improvement was made to the railstop model in RADTRAN-II, which calculates the occupational and public dose accumulated as a truck or train is stopped during transit. The primary basis for the change is a survey performed by an expert in railroad operations and documented by Ostmeyer (1985a). The railstop-exposure model can treat both general-freight and "dedicated-train" (see Section A.13.4.3) shipments. The model classifies railstop exposures into two types: employee proximity exposures and general rail-and-nonrail population exposures. The proximity exposures are received by employees who handle waste shipments at railstops. In the case of general-freight shipments, these exposures result from train classifications, car repair, and train inspections. The dedicated-train proximity exposures result from train inspections and car repairs. General rail-and-nonrail exposures are received by railyard employees not handling the shipment and the general population that surrounds the railyard. Unlike crew proximity exposures, which depend on the number of train "handlings," general-population exposures depend on railstop duration.

Another major change to RADTRAN II is the addition of a food-ingestion model. Population doses from food ingestion are estimated by using radionuclide transfer fractions. The model is documented by Ostmeyer et al.

(1985b). Population food exposures are estimated only for accidents that occur in rural areas. However, because of the nature of the model, food-ingestion doses are not limited to the residents of rural areas.

Food transfer fractions were determined for cobalt, cesium, strontium, and plutonium radionuclides. All other radionuclides will make negligible contributions to food-pathway risks for waste-transportation accidents. Each transfer fraction represents the "time-integrated" transfer of the radionuclide through the food-ingestion pathway. Transfer fractions were determined by using both empirical fallout data and systems-analysis models.

The occupational and nonoccupational nonradiological risks for rail accidents were updated to be consistent with the most recent edition of National Transportation Statistics (DOT, 1985). In addition, the calculation of risk associated with dedicated trains was updated to incorporate the appropriate statistical base. Two years of accident data, 1982 and 1983, are cited in this document; to obtain statistics for the analysis performed here, the data for both years were averaged.

For calculating all of the radiological and nonradiological risks associated with incident-free rail transportation, input must be in terms of fatalities per railcar-kilometer and injuries per railcar-kilometer. For general-commerce rail transportation, average occupational and nonoccupational accident-related fatalities are divided by the appropriate average values for railcar-kilometers of Class I freight. The number of injuries are derived from the numbers of fatalities.

However, unlike all radiological risks and incident-free nonradiological pollution risks, which depend on train length, the nonradiological-accident term is dominated by grade-crossing accidents, whose occurrence depends solely on the number of trains rather than the length of trains carrying radioactive waste. Consequently, for dedicated trains only, the unit risk factors are expressed in terms of risk per train rather than risk per railcar. Dedicated trains are assumed for shipments from the MRS facility. Further details are given by Cashwell et al. (1985).

Finally, a method was developed for modifying unit-risk factors to reflect changes in population densities. A brief discussion of this method is presented below.

In the relationships given below, five symbols are used. They are defined as follows:

- F_1 = A zone- and material-dependent risk factor based on rural, suburban, and urban population densities of 6, 719, and 3,861 persons per square kilometer, respectively.
- F_2 = Any revision to F_1 desired because of a change in population density.
- $\$1$ = One of the population densities (6, 719, or 3,861 persons per square kilometer).
- $\$2$ = The altered value of a population density.

a= The fraction of the normal nonoccupational radiological risk contributed by offlink exposures to the general population [$a = \text{offlink}/(\text{onlink} + \text{stops} + \text{offlink})$].

The following values of the quantity a were used for each mode and population zone:

Mode	Rural	Suburban	Urban
Truck	0.00	0.18	0.07
Train	0.03	0.85	0.47
Dedicated Train	0.23	0.97	0.76

The resultant radiological and nonradiological risk factors are as follows:

Radiological Risks

Normal occupational fatalities	Unchanged
Normal nonoccupational fatalities	$F_2 = F_1[a(\$_2/\$_1) + (1 - a)]$
Accident nonoccupational fatalities	$F_2 = (\$_2/\$_1)F_1$

Nonradiological Risks

Normal nonoccupational fatalities	$F_2 = (\$_2/\$_1)F_1$
Accident occupational fatalities	Unchanged
Accident nonoccupational fatalities	Unchanged
Accident injuries	Unchanged

A.8.3.4 Transportation scenarios evaluated for risk analysis

The DOE has described two different waste-management systems in the Mission Plan (DOE, 1985): an authorized system and an improved-performance system. In the authorized system, spent fuel and defense high-level waste would be shipped directly from the sources (reactors and waste sources) to the repository. In the improved-performance system, a centrally located MRS facility would be used to prepare the spent fuel for disposal in the repository.

The rate at which the repository would accept spent fuel and high-level waste is given in Table A-6 for the authorized system. The high-level waste is assumed to be sent directly to the repository under either plan. The volume of defense waste that is used for this analysis is greater than that presented in the Mission Plan in order not to underestimate the environmental impact of transporting this waste.

Several cases are considered for the improved performance system; they are defined by changes to two inputs: (1) the size of the cask used to transport waste to the repository from the MRS facility and (2) the location to which reactors west of the Rocky Mountains (longitude 100°W) ship their spent fuel. Two cask sizes were considered: 100 and 150 tons. Reactors west

Table A-6. Repository waste-acceptance schedule for the authorized system
(metric tons of uranium)

Year	Spent fuel	High-level waste ^{a, b}			
		Savannah River	INEL ^c	Hanford	West Valley ^d
1998	400				
1999	400				
2000	400				
2001	900				
2002	1,800				
2003	3,000	350		75	20
2004	3,000	350		75	20
2005	3,000	350		75	20
2006	3,000	350		75	20
2007	3,000	350		75	20
2008	3,000	200	300	75	20
2009	3,000	200	300	75	20
2010	3,000	200	300	75	20
2011	3,000	200	300	75	20
2012	3,000	200	300	75	20
2013	3,000	200	300	75	20
2014	3,000	200	300	75	20
2015	3,000	200	300	75	20
2016	3,000	350	300	75	20
2017	3,000	350	300	75	20
2018	3,000	350	300		20
2019	3,000	350	300		20
2020	3,000	350	300		20
2021	3,000	350	300		20
2022	1,100	350	300		20

^a A canister of high-level waste contains the fission products from the reprocessing of 0.5 MTU of spent fuel.

^b The values given for high-level waste were developed for use in these EAs. They are believed to be maximum values that would not be exceeded and do not reflect expected values. They do not compare with the values given in the Mission Plan (DOE, 1985).

^c Idaho National Engineering Laboratory.

^d Commercial high-level waste from the West Valley Demonstration Project.

of longitude 100°W were assumed to ship either directly to the repository or to the MRS facility. All four combinations were considered. The waste-acceptance rates for the MRS facility and the repository are given in Tables A-7 and A-8 for the two cases involving different destinations for the spent fuel from western reactors.

A.8.3.5 Assumption about wastes

Detailed descriptions of the spent fuel and miscellaneous wastes are given by Cashwell et al. (1985); however, some basic assumptions fundamental to the risk analysis are presented here.

The spent fuel was assumed to be 5 years old if shipped from the reactors and 10 years old if shipped from the MRS facility. In order to bound the consequences, all analyses assume that the composition of the radionuclide release during postulated accidents is derived from a pressurized-water reactor. The fuel burnup was assumed to be 33,000 MWd/MTU. It was assumed that the spent-fuel assemblies have limited amounts of radioactivity ("crud") on their exterior surfaces; this can be knocked loose and readily released to the inside of a cask under accident conditions. Spent fuel shipped from the MRS facility is consolidated and shipped either in a thin-wall repository-specific canister or encapsulated in a container designed specifically for disposal in one of the different repository host rocks. (The repository-specific canisters would be encapsulated in disposal containers at the repository.).

The high-level waste—defense high-level waste from three reprocessing plants and commercial high-level waste from West Valley Demonstration Project—was assumed to have the composition of defense waste from the Savannah River Plant. Therefore, each canister of waste was assumed to contain the inventory resulting from the processing of 0.5 MTU of spent fuel. The waste matrix was assumed to be a glass.

The wastes resulting from fuel consolidation—hardware, high-activity low-level waste, and contact-handled transuranic waste (CH-TRU)—were assumed to be shipped along with consolidated spent fuel to the repository. The hardware contains activation products; the high-activity low-level waste also has significant amounts of fission products; and the contact-handled transuranic waste contains mainly transuranic radionuclides, which pose no particular external radiation hazard. The high-activity low-level waste and the hardware are placed in drums and then five drums are loaded into a canister; the transuranic waste is packed in drums.

A.8.3.6 Operational considerations in risk analysis

Shipments from the reactors and HLW processing plants are made by truck or rail in general-commerce shipments. Cask sizes are limited so that no special restrictions are encountered enroute. Shipments from the MRS facility, however, are made in dedicated trains that haul only the radioactive material being shipped to the repository. The reference dedicated train

Table A-7. Receipt rates for scenario involving all reactors shipping to an MRS facility

Year	Spent fuel ^a (MTU)		Secondary waste products to repository		
	All reactors to MRS	MRS to repository	Hardware (canisters)	High-activity waste (canisters)	CH-TRU ^b (drums)
1996	400				
1997	1,800				
1998	3,000	400	35	33	74
1999	3,000	400	35	33	74
2000	3,000	400	35	33	74
2001	3,000	900	79	74	166
2002	3,000	1,800	158	147	331
2003	3,000	3,000	264	246	552
2004	3,000	3,000	264	246	552
2005	3,000	3,000	264	246	552
2006	3,000	3,000	264	246	552
2007	3,000	3,000	264	246	552
2008	3,000	3,000	264	246	552
2009	3,000	3,000	264	246	552
2010	3,000	3,000	264	246	552
2011	3,000	3,000	264	246	552
2012	3,000	3,000	264	246	552
2013	3,000	3,000	264	246	552
2014	3,000	3,000	264	246	552
2015	3,000	3,000	264	246	552
2016	3,000	3,000	264	246	552
2017	2,800	3,000	264	246	552
2018		3,000	264	246	552
2019		3,000	264	246	552
2020		3,000	264	246	552
2021		3,000	264	246	552
2022		1,100	97	90	202

^a Spent fuel only; high-level waste is assumed to be shipped directly to a repository in the improved-performance system, bypassing the MRS facility (see Table A-6).

^b Contact-handled transuranic waste.

Table A-8. Facility receipt rates for scenario involving only eastern reactors shipping to an MRS facility

Year	Spent fuel (MTU)			Secondary waste products to repository		
	Eastern reactors to MRS	Western reactors to repository	MRS to repository	Hardware (canisters)	High-activity waste (canisters)	CH-TRU (drums)
1996	370					
1997	1,665					
1998	2,775	30	370	32	31	68
1999	2,775	30	370	32	31	68
2000	2,775	30	370	32	31	68
2001	2,775	67.5	832.5	73	68	154
2002	2,775	135	1,665	146	228	306
2003	2,775	225	2,775	244	228	511
2004	2,775	225	2,775	244	228	511
2005	2,775	225	2,775	244	228	511
2006	2,775	225	2,775	244	228	511
2007	2,775	225	2,775	244	228	511
2008	2,775	225	2,775	244	228	511
2009	2,775	225	2,775	244	228	511
2010	2,775	225	2,775	244	228	511
2011	2,775	225	2,775	244	228	511
2012	2,775	225	2,775	244	228	511
2013	2,775	225	2,775	244	228	511
2014	2,775	225	2,775	244	228	511
2015	2,775	225	2,775	244	228	511
2016	2,590	225	2,775	244	228	511
2017	2,800	225	2,775	244	228	511
2018		225	2,775	244	228	511
2019		225	2,775	244	228	511
2020		225	2,775	244	228	511
2021		225	2,775	244	228	511
2022		82.5	1,017.5	90	83	187

consists of five spent-fuel casks, two hardware casks, two high-activity-waste casks, and one railcar carrying contact-handled transuranic waste. The dedicated train has different operational characteristics than a general-commerce train, and the analyses reflect those differences.

A.8.3.7 Values for factors needed to calculate population risks

As described in Section A.8.3.1, four factors are needed to assess the population risks from waste transportation: unit risk factors, shipment distances, fractions of travel in various population zones, and the number of shipments.

Tables A-9 through A-12 present all of the unit risk factors used in the analyses made for this environmental assessment. Tables A-9 and A-10 give the factors for shipments that originate at the reactors and the HLW processing plants. The unit risk factors are given for truck and rail shipment and for each population zone. All rail factors are for an individual railcar in general commerce. Table A-9 presents estimates of the radiological risks from normal transportation and accidents. The normal risk is subdivided into occupational and nonoccupational categories. The accident risk is not divided by occupational category because potential exposures for each category are similar (see Section A.8.1.2), and the population density used in the calculations can be considered to include both categories. Table A-10 presents estimates of the nonradiological risk.

Tables A-11 and A-12 contain risk factors for shipments that originate at the MRS facility. Separate factors are given for consolidated-fuel shipments in both the 100- and 150-ton casks and for the secondary wastes that are generated in consolidation. All shipments from the MRS facility were assumed to be by dedicated train, and therefore the unit risk factors are for a complete train (i.e., the factors are on a train-mile, rather than a railcar-mile, basis).

Shipment distances are found in Tables A-13 and A-14. Table A-13 gives the distances from a few chosen reactors in different regions of the United States to the MRS facility and each repository site and from the MRS facility to each repository site. A complete listing of reactors can be found in the report by Cashwell et al. (1985). Table A-14 shows the distances from the HLW sites to the various repository sites. A summary of total shipment distances is given in Table A-15 for each transportation scenario evaluated for the authorized system and the improved-performance system. Distances are given for the cases where shipments are made by all truck or all rail. For two of the scenarios estimates are given for each waste type to provide a perspective on the contribution of each.

The fractions of travel in the various population zones are found in Tables A-16 and A-17 for the selected reactors and the HLW processing sites, respectively. Routes from each source are analyzed to determine the approximate amount of travel in each of the population ones. Further details and all remaining reactor data can be found in the report by Cashwell et al. (1985).

Table A-9. Radiological risk factors for shipments from waste sources to a repository or MRS facility^a

Mode	Zone	Hazard group	Spent fuel ^b	DHLW ^c	WVHLW ^d
Truck	Rural	Normal occupational fatalities	4.70E-09 ^e	4.14E-09	4.14E-09
Truck	Rural	Normal nonoccupational fatalities	2.84E-08	2.54E-08	2.54E-08
Truck	Rural	Accident nonoccupational fatalities	3.10E-13	2.56E-13	1.79E-13
Truck	Suburban	Normal occupational fatalities	1.03E-08	9.10E-09	9.10E-09
Truck	Suburban	Normal nonoccupational fatalities	4.36E-08	3.92E-08	3.92E-08
Truck	Suburban	Accident nonoccupational fatalities	7.46E-10	1.08E-10	7.60E-11
Truck	Urban	Normal occupational fatalities	1.72E-08	1.52E-08	1.52E-08
Truck	Urban	Normal nonoccupational fatalities	5.96E-08	5.36E-08	5.36E-08
Truck	Urban	Accident nonoccupational fatalities	1.22E-09	2.16E-10	1.52E-10
Rail	Rural	Normal occupational fatalities	2.14E-09	2.04E-09	1.03E-09
Rail	Rural	Normal nonoccupational fatalities	1.15E-09	1.03E-09	1.03E-09
Rail	Rural	Accident nonoccupational fatalities	1.34E-12	5.56E-13	5.40E-13
Rail	Suburban	Normal occupational fatalities	2.14E-09	2.04E-09	2.04E-09
Rail	Suburban	Normal nonoccupational fatalities	7.70E-09	6.90E-09	6.90E-09
Rail	Suburban	Accident nonoccupational fatalities	2.78E-09	2.72E-10	2.64E-10
Rail	Urban	Normal occupational fatalities	2.14E-09	2.04E-09	2.04E-09
Rail	Urban	Normal nonoccupational fatalities	2.58E-09	2.32E-09	2.32E-09
Rail	Urban	Accident nonoccupational fatalities	6.72E-09	5.08E-09	4.92E-09

^a Radiological risk factors per kilometer of travel. To convert factors to risk per mile, multiply by 1.609. Based on 1 man-rem = 2×10^{-4} latent-cancer fatality plus first- and second-generation genetic effects.

^b Unit risk factors for general-commerce truck and rail transportation of spent fuel; units are per kilometer for truck and per railcar-kilometer for rail.

^c Unit risk factors for general-commerce truck and rail transportation of defense high-level wastes; units are per kilometer for truck and per railcar-kilometer for rail.

^d Unit risk factors for general-commerce truck and rail transportation of commercial high-level waste from West Valley; units are per kilometer for truck and per railcar-kilometer for rail.

^e $4.70E-09 = 4.7 \times 10^{-9}$.

Table A-10. Nonradiological risk factors for shipments from waste sources to a repository or MRS facility^a

Mode	Zone	Hazard group	Spent-fuel ^b	DFHLW ^c	WVHLW ^d
Truck	Rural	Normal nonoccupational fatalities	0.00E+00	0.00E+00	0.00E+00
Truck	Rural	Accident occupational fatalities	1.50E-08 ^e	1.50E-08	1.50E-08
Truck	Rural	Accident nonoccupational fatalities	5.30E-08	5.30E-08	5.30E-08
Truck	Rural	Accident occupational injuries	2.80E-08	2.80E-08	2.80E-08
Truck	Rural	Accident nonoccupational injuries	8.00E-07	8.00E-07	8.00E-07
Truck	Suburban	Normal nonoccupational fatalities	0.00E+00	0.00E+00	0.00E+00
Truck	Suburban	Accident occupational fatalities	3.70E-09	3.70E-09	3.70E-09
Truck	Suburban	Accident nonoccupational fatalities	1.30E-08	1.30E-08	1.30E-08
Truck	Suburban	Accident occupational injuries	1.30E-08	1.30E-08	1.30E-08
Truck	Suburban	Accident nonoccupational injuries	3.80E-07	3.80E-07	3.80E-07
Truck	Urban	Normal nonoccupational fatalities	1.00E-07	1.00E-07	1.00E-07
Truck	Urban	Accident occupational fatalities	2.10E-09	2.10E-09	2.10E-09
Truck	Urban	Accident nonoccupational fatalities	7.50E-09	7.50E-09	7.50E-09
Truck	Urban	Accident occupational injuries	1.30E-08	1.30E-08	1.30E-08
Truck	Urban	Accident nonoccupational injuries	3.70E-07	3.70E-07	3.70E-07
Rail	Rural	Normal nonoccupational fatalities	0.00E+00	0.00E+00	0.00E+00
Rail	Rural	Accident occupational fatalities	1.81E-09	1.81E-09	1.81E-09
Rail	Rural	Accident nonoccupational fatalities	2.64E-08	2.64E-08	2.64E-08
Rail	Rural	Accident occupational injuries	2.46E-07	2.46E-07	2.46E-07
Rail	Rural	Accident nonoccupational injuries	5.12E-08	5.12E-08	5.12E-08
Rail	Suburban	Normal nonoccupational fatalities	0.00E+00	0.00E+00	0.00E+00
Rail	Suburban	Accident occupational fatalities	1.81E-09	1.81E-09	1.81E-09
Rail	Suburban	Accident nonoccupational fatalities	2.64E-08	2.64E-08	2.64E-08
Rail	Suburban	Accident occupational injuries	2.46E-07	2.46E-07	2.46E-07
Rail	Suburban	Accident nonoccupational injuries	5.12E-08	5.12E-08	5.12E-08
Rail	Urban	Normal nonoccupational fatalities	1.30E-07	1.30E-07	1.30E-07
Rail	Urban	Accident occupational fatalities	1.81E-09	1.81E-09	1.81E-09
Rail	Urban	Accident nonoccupational fatalities	2.64E-08	2.64E-08	2.64E-08
Rail	Urban	Accident occupational injuries	2.46E-07	2.46E-07	2.46E-07
Rail	Urban	Accident nonoccupational injuries	5.12E-08	5.12E-08	5.12E-08

^a Nonradiological risk factors per kilometer of travel. To convert factors to risk per mile, multiply by 1.609.

^b Unit risk factors for general-commerce truck and rail transportation of spent fuel, units are per kilometer for truck, per railcar-kilometer for normal rail, and per train-kilometer for rail accidents. (Note: for general-commerce rail, 1 train-kilometer is equivalent to 1 railcar-kilometer.)

^c Unit risk factors for general-commerce truck and rail transportation of defense high-level waste; units are per kilometer for truck, per railcar-kilometer for normal rail, and per train-kilometer for rail accidents. (Note: For general-commerce rail, 1 train-kilometer is equivalent to 1 railcar-kilometer.)

^d Unit risk factors for general-commerce truck and rail transportation of commercial high-level waste from West Valley; units are per kilometer for truck, per railcar-kilometer for normal rail, and per train-kilometer for rail accidents. (Note: For general-commerce rail, 1 train-kilometer is equivalent to 1 railcar-kilometer.)

^e 1.50E-08 = 1.5 x 10⁻⁸.

Table A-11. Radiological risk factors for shipments from MRS facility^A

Mode	Zone	Hazard group	Consolidated spent fuel					
			100-ton cask			150-ton cask		
			MRS-salt ^B	MRS-tuff ^B	MRS-basalt ^B	MRS-salt ^B	MRS-tuff ^B	MRS-basalt ^B
Rail	Rural	Normal occupational fatalities	6.68E-10	6.68E-10	6.68E-10	6.68E-10	6.68E-10	6.68E-10
Rail	Rural	Normal nonoccupational fatalities	8.32E-10 ^C	8.32E-10	8.32E-10	8.32E-10	8.32E-10	8.32E-10
Rail	Rural	Accident non-occupational fatalities	6.58E-12	4.88E-12	6.56E-12	1.76E-11	1.22E-11	2.02E-11
Rail	Suburban	Normal occupational fatalities	6.68E-10	6.68E-10	6.68E-10	6.68E-10	6.68E-10	6.68E-10
Rail	Suburban	Normal nonoccupational fatalities	3.36E-08	3.36E-08	3.36E-08	3.36E-08	3.36E-08	3.36E-08
Rail	Suburban	Accident nonoccupational fatalities	1.29E-08	9.88E-09	1.29E-08	3.46E-08	2.38E-08	3.94E-08
Rail	Urban	Normal occupational fatalities	6.68E-10	6.68E-10	6.68E-10	6.68E-10	6.68E-10	6.68E-10
Rail	Urban	Normal nonoccupational fatalities	7.98E-09	7.98E-09	7.98E-09	7.98E-09	7.98E-09	7.98E-09
Rail	Urban	Accident nonoccupational fatalities	3.10E-08	2.38E-08	3.10E-08	8.30E-08	5.76E-08	9.50E-08
Mode	Zone	Hazard group	Secondary wastes					
			100-ton Cask			150-ton Cask		
			MRS-HRDWR ^D	MRS-HAW ^E	MRS-TRU ^F	MRS-HRDWR ^D	MRS-HAW ^E	MRS-TRU ^F
Rail	Rural	Normal occupational fatalities	2.68E-10	2.68E-10	1.56E-10	2.68E-10	2.68E-10	1.56E-10
Rail	Rural	Normal nonoccupational fatalities	3.34E-10	3.34E-10	2.40E-10	3.34E-10	3.34E-10	2.40E-10
Rail	Rural	Accident nonoccupational fatalities	3.46E-16	2.34E-11	3.28E-17	8.50E-16	3.98E-11	3.28E-17
Rail	Suburban	Normal occupational fatalities	2.68E-10	2.68E-10	1.56E-10	2.68E-10	2.68E-10	1.56E-10
Rail	Suburban	Normal nonoccupational fatalities	1.34E-08	1.34E-08	9.66E-09	1.34E-08	1.34E-08	9.66E-09
Rail	Suburban	Accident nonoccupational fatalities	3.58E-14	2.12E-08	2.28E-14	9.80E-14	3.62E-08	2.28E-14
Rail	Urban	Normal occupational fatalities	2.68E-10	2.68E-10	1.56E-10	2.68E-10	2.68E-10	1.56E-10
Rail	Urban	Normal nonoccupational fatalities	3.20E-09	3.20E-09	2.30E-09	3.20E-09	3.20E-09	2.30E-09
Rail	Urban	Accident nonoccupational fatalities	1.80E-13	3.86E-07	4.18E-13	2.74E-13	6.64E-07	4.18E-13

^A To convert factors to risk per mile, multiply by 1.609. Based on 1 man-rem = 2×10^{-4} latent-cancer fatality plus first- and second-generation genetic effects.

^B Unit risk factors for dedicated-rail transportation of consolidated spent fuel packaged for shipment to either a salt repository, a tuff repository, or a basalt repository, expressed as risk per 5 railcar-kilometers.

^C Unit risk factors for dedicated-rail transportation of the transuranic waste (TRU) generated during spent-fuel consolidation, expressed as risk per 1 railcar-kilometer.

^D Unit risk factors for dedicated-rail transportation of spent-fuel-assembly hardware expressed as risk per 2 railcar-kilometers; packaging is the same regardless of repository site.

^E Unit risk factors for dedicated-rail transportation of high-activity low-level waste (HAW) generated during spent-fuel consolidation, expressed as risk per 2 railcar-kilometers; packaging is the same regardless of repository site.

Table A-12. Nonradiological risk factors for shipments from MRS facility^A

Mode	Zone	Hazard group	Consolidated spent fuel ^B	Secondary waste		
			MRS-repository	MRS-HRDWR ^C	MRS-HAW ^D	MRS-TRU ^E
Rail	Rural	Normal nonoccupational fatalities	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rail	Rural	Accident occupational fatalities	1.27E-07 ^F	0.00E+00	0.00E+00	0.00E+00
Rail	Rural	Accident nonoccupational fatalities	1.85E-06	0.00E+00	0.00E+00	0.00E+00
Rail	Rural	Accident occupational injuries	1.74E-05	0.00E+00	0.00E+00	0.00E+00
Rail	Rural	Accident non-occupational injuries	3.60E-06	0.00E+00	0.00E+00	0.00E+00
Rail	Suburban	Normal nonoccupational fatalities	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rail	Suburban	Accident occupational fatalities	1.27E-07	0.00E+00	0.00E+00	0.00E+00
Rail	Suburban	Accident nonoccupational fatalities	1.85E-06	0.00E+00	0.00E+00	0.00E+00
Rail	Suburban	Accident Occupational Injuries	1.74E-05	0.00E+00	0.00E+00	0.00E+00
Rail	Suburban	Accident Non-occupational Injuries	3.60E-06	0.00E+00	0.00E+00	0.00E+00
Rail	Urban	Normal nonoccupational fatalities	6.50E-07	2.60E-07	2.60E-07	1.30E-07
Rail	Urban	Accident occupational fatalities	1.27E-07	0.00E+00	0.00E+00	0.00E+00
Rail	Urban	Accident nonoccupational fatalities	1.85E-06	0.00E+00	0.00E+00	0.00E+00
Rail	Urban	Accident Occupational Injuries	1.74E-05	0.00E+00	0.00E+00	0.00E+00
Rail	Urban	Accident Non-occupational Injuries	3.60E-06	0.00E+00	0.00E+00	0.00E+00

^A Nonradiological risk factors per kilometer of travel. To convert factors to risk per mile, multiply by 1.609.

^B Unit risk factors for dedicated-rail transportation of spent fuel in 100- and 150-ton casks to a salt repository, a tuff repository, or a basalt repository; expressed as risk per kilometer for normal transportation and as risk per train-kilometer for accidents.

^C Unit risk factors for dedicated-rail transportation of spent-fuel-assembly hardware, expressed as risk per railcar-kilometer for normal transportation and as risk per train-kilometer for accidents; packaging is not affected by repository site.

^D Unit risk factors for dedicated-rail transportation of the high-activity low-level waste (HAW) generated during the consolidation of spent fuel; expressed as risk per railcar-kilometer for normal transportation and as risk per train-kilometer for accidents.

^E Unit risk factors for dedicated-rail transportation of the contact-handled transuranic waste (TRU) generated during the consolidation of spent fuel; expressed as risk per railcar-kilometer for normal transportation and as risk per train-kilometer for accidents.

Table A-13. Distance per shipment from selected^a
reactors and the MRS facility

Reactor	Distance (miles)					
	Salt		Davis Canyon	Tuff (Yucca Mt.)	Basalt (Hanford)	MRS (Oak Ridge)
	Richton	Deaf Smith				
Maine Yankee (Maine)						
Truck	1,570	2,150	2,570	3,040	3,107	1120
Rail	1,920	2,180	2,750	3,270	3,150	1480
Crystal River (Florida)						
Truck	579	1,670	2,310	2,600	2,990	639
Rail	571	1,699	2,450	3,000	3,210	698
Quad-Cities (Illinois)						
Truck	959	1,040	1,300	1,780	1,910	714
Rail	1,080	937	1,480	2,000	1,980	861
Palo Verde (Arizona)						
Truck	1,908	789	509	606	1,550	1920
Rail	1,950	933	1,790	652	1,690	2290
Trojan (Oregon)						
Truck	2,780	1,850	1,190	1,330	302	2630
Rail	2,919	2,210	1,250	1,460	301	2890
MRS facility						
Truck	NA ^b	NA	NA	NA	NA	NA
Rail	520	1,410	1,950	1,470	1,620	NA

^a These reactors were chosen as representative of regions throughout the country.

^b NA = not applicable.

Table A-14. Distance per shipment from
sources of high-level waste

Source	Distance (miles)				
	Salt			Tuff	Basalt
	Richton	Deaf Smith	Davis Canyon	(Yucca Mt.)	(Hanford)
Hanford					
Truck	2,610	1,660	1,010	1,150	NA ^a
Rail	2,670	1,730	1,070	1,288	NA
Idaho National Engineering Laboratory					
Truck	2,160	1,210	604	740	610
Rail	2,110	1,200	555	763	696
Savannah River Plant					
Truck	568	1,420	2,060	2,350	2,740
Rail	644	1,520	2,200	2,750	2,890
West Valley					
Truck	1,160	1,580	2,000	2,750	2,550
Rail	1,450	1,690	2,100	2,860	2,660

^a NA = not applicable.

^b Commercial high-level waste.

Table A-15. Total cask-miles for shipments in the authorized and the improved-performance systems (one-way million miles)

Mode and waste type	Repository site				
	Salt			Tuff	Basalt
	Richton	Deaf Smith	Davis Canyon	(Yucca Mt.)	(Hanford)
AUTHORIZED SYSTEM					
100% truck					
Spent fuel	67.4	94.4	115.1	141.8	149.7
Defense high-level waste	28.0	26.0	28.0	33.0	35.0
Commercial high-level waste ^a	1.0	1.0	2.0	2.0	2.0
100% rail					
Spent fuel	11.0	15.4	18.8	23.2	24.6
Defense high-level waste	6.5	6.1	6.5	7.6	8.4
Commercial high-level waste ^a	0.2	0.2	0.2	0.3	0.3
Totals					
Truck from origin	96.4	121.4	145.1	176.8	186.7
Rail from origin	17.7	21.7	25.5	31.1	33.3
IMPROVED-PERFORMANCE SYSTEM					
1. All fuel to MRS facility					
100% truck from origin					
Spent fuel	48.8	48.8	48.8	48.8	48.8
Defense high-level waste	28.0	26.0	28.0	33.0	35.0
Commercial high-level waste ^a	1.0	1.0	2.0	2.0	2.0
100% rail from origin					
Spent fuel	8.0	8.0	8.0	8.0	8.0
Defense high-level waste	6.5	6.1	6.5	7.6	8.4
Commercial high-level waste ^a	0.2	0.2	0.2	0.3	0.3
Rail from MRS facility ^b					
100-ton casks ^c	6.3	15.3	20.6	26.3	25.0
150-ton casks ^c	2.1	5.0	6.7	11.2	8.7
Totals, 100-ton casks					
Truck from origin ^d	84.1	91.1	98.9	110.1	110.8
Rail from origin	21.0	29.6	35.3	42.2	41.7
Totals, 150-ton casks					
Truck from origin ^d	79.9	80.8	85.0	95.0	94.5
Rail from origin	16.8	19.3	21.4	27.1	25.4
2. Western-reactor spent fuel to repository					
Totals, 100-ton casks					
Truck from origin ^d	83.7	85.1	90.4	99.8	101.4
Rail from origin	20.5	27.6	32.5	38.6	38.4
Totals, 150-ton casks					
Truck from origin ^d	80.0	75.8	77.0	86.4	86.8
Rail from origin	16.7	18.3	19.0	25.1	23.8

^a Waste from West Valley Demonstration Project.

^b All shipments in dedicated trains.

^c Includes casks carrying secondary wastes.

^d Totals for the improved-performance system include both truck shipments from origin to the MRS facility and dedicated-rail shipments from the MRS facility to the repository.

Table A-16. Fraction of travel in population zones from selected reactors and the MRS^a

Reactor	Richton		Salt		Davis Canyon		Tuff (Yucca Mt.)		Basalt (Hanford)		MRS Facility	
	Truck Rail		Deaf Smith		Truck Rail		Truck Rail		Truck Rail		Truck Rail	
	Truck	Rail	Truck	Rail	Truck	Rail	Truck	Rail	Truck	Rail	Truck	Rail
Maine Yankee (Maine)												
Urban	.01	.02	.01	.03	.01	.01	.01	.01	.01	.02	.01	.03
Suburban	.43	.48	.35	.34	.28	.23	.26	.21	.26	.27	.48	.49
Rural	.57	.50	.64	.63	.71	.76	.74	.78	.73	.71	.51	.48
Crystal River (Florida)												
Urban	0	.01	.01	.02	0	.01	.01	.01	.01	.01	0	.01
Suburban	.19	.18	.23	.24	.22	.17	.17	.16	.19	.18	.32	.26
Rural	.81	.81	.77	.74	.78	.82	.82	.83	.80	.82	.68	.73
Quad-Cities (Illinois)												
Urban	0	.02	0	0	.01	.01	0	.01	0	.01	0	.04
Suburban	.19	.24	.18	.13	.11	.08	.12	.09	.10	.12	.33	.24
Rural	.81	.74	.82	.86	.88	.91	.88	.90	.90	.87	.67	.72
Palo Verde (Arizona)												
Urban	.01	.03	.02	.01	.02	.02	.02	.01	.02	.02	.01	.01
Suburban	.15	.19	.09	.10	.08	.20	.14	.09	.23	.25	.14	.15
Rural	.84	.78	.89	.90	.90	.78	.85	.90	.75	.73	.84	.84
Trojan (Oregon)												
Urban	0	.01	.01	.01	0	.01	0	.02	0	.01	0	.01
Suburban	.16	.11	.13	.09	.19	.14	.18	.10	.35	.17	.17	.11
Rural	.84	.88	.86	.90	.80	.85	.82	.89	.64	.82	.83	.88
MRS facility (Tennessee)												
Urban		.01		.02		.02		.02		.01		
Suburban	NA ^b	.30	NA	.16	NA	.12	NA	.12	NA	.11	NA	NA
Rural		.69		.82		.87		.86		.88		

^a These reactors were chosen as representative of regions throughout the country.^b NA = not applicable.

Table A-17. Fraction of travel in population zones from high-level waste sources

Waste source	<u>Richton</u>		<u>Salt</u>		<u>Davis Canyon</u>		<u>Tuff</u>		<u>Basalt</u>	
	Truck	Rail	Truck	Rail	Truck	Rail	Truck	Rail	Truck	Rail
Hanford										
Urban	.01	0	.01	.01	0	0	0	.01	NA	NA
Suburban	.16	.11	.12	.10	.19	.15	.18	.10	NA	NA
Rural	.84	.89	.87	.89	.81	.84	.82	.89	NA	NA
Idaho National										
Engr Lab										
Urban	0	.01	.01	.01	.01	.01	.01	.01	0	0
Suburban	.15	.10	.10	.11	.21	.22	.19	.11	.15	.12
Rural	.85	.90	.89	.88	.78	.77	.80	.88	.85	.88
Savannah River Plant										
Urban	.01	.03	.01	.02	0	.02	.01	.02	0	.01
Suburban	.30	.26	.23	.21	.22	.19	.17	.21	.19	.17
Rural	.69	.72	.76	.78	.77	.79	.82	.78	.81	.82
West Valley										
Urban	.01	.03	0	.02	.01	.02	.01	.02	.01	.01
Suburban	.32	.33	.30	.21	.22	.18	.20	.21	.21	.17
Rural	.67	.64	.70	.78	.77	.80	.79	.78	.78	.82

The numbers of shipments from each reactor to the repository and to the MRS facility are given in Tables A-18 and A-19, respectively. The numbers are different because of the difference in the waste-acceptance schedules for the authorized system and the improved-performance system (see Tables A-6 and A-7). Table A-20 provides information on the numbers of shipments to the repository or MRS facility and the numbers of shipments from the MRS facility.

A.8.3.8 Results of population-risk analyses

The risks of radioactive-material transportation must be evaluated for both radiological and nonradiological effects. Since a package does emit small amounts of radiation, a shipment exposes the public during all phases of its journey. People are exposed at stops and along routes even when the package is moving. In addition to the radiological effects, transportation increases the levels of air pollution. Any equivalent-weight shipment of potatoes, bricks, or other nonradioactive materials would have the same effect, but that effect must be evaluated for a complete analysis. In fact, even in most transportation accidents, the traumatic injuries and deaths resulting from an impact or a fire may far outweigh any radiological consequences. Accordingly, in evaluating the potential consequences or risk of any radioactive-material shipment, the injuries and deaths from both radiological and nonradiological causes must be considered.

Tables A-21, A-22, and A-23 summarize the results of the analysis for each of the scenarios evaluated for the authorized system and the improved-performance system. Table A-21, for the authorized system, estimates the total radiological and nonradiological risks for each of the sites and for the cases where all shipments are assumed to be made by truck or by rail. Table A-22 which estimates risks for the improved performance system, shows the results for shipments from the MRS facility in 100-ton casks, which carry disposal containers ready for emplacement in the repository and 150 ton casks which carry thin-wall canisters. Table A-23 is analogous to Table A-22 except that it presents results for the scenarios in which spent fuel from Western reactors is sent directly to the repository, rather than the MRS facility. In all scenarios it was assumed that both defense and commercial high-level waste would be shipped directly to the repository.

Results for two scenarios (the authorized system and one case for the improved-performance system) are presented in more detail in Tables A-24 through A-31. Results are presented by waste type, normal or accident conditions, and population group. Similar details are available in the report by Cashwell et al. (1985) for all scenarios evaluated for this environmental assessment.

Table A-18. Number of shipments to a repository from
each reactor site (authorized system)

Reactor name	100% Truck	100% Rail	Reactor name	100% Truck	100% Rail
Farley 1	120	18	Millstone 1	804	111
Farley 2	46	7	Millstone 2	805	106
Palo Verde 1	511	72	Millstone 3	36	6
Palo Verde 2	484	70	Monticello	693	96
Palo Verde 3	448	63	Prairie Island 1	650	92
Arkansas Nuclear One 1	762	108	Prairie Island 2	631	90
Arkansas Nuclear One 2	187	27	Fort Calhoun 1	534	76
Calvert Cliffs 1	893	127	Humboldt Bay	86	12
Calvert Cliffs 2	853	122	Diablo Canyon 2	236	34
Pilgrim 1	761	105	Diablo Canyon 1	279	40
Robinson 2	581	83	Susquehanna 1	652	90
Brunswick 2	799	111	Susquehanna 2	614	85
Brunswick 1	791	109	Peach Bottom 2	1126	156
Perry 1	806	110	Peach Bottom 3	1126	156
Perry 2	747	104	Limerick 1	679	95
Dresden 1	136	18	Limerick 2	421	59
Dresden 2	909	126	Trojan	330	18
Dresden 3	825	114	Fitzpatrick	614	107
Quad Cities 1	862	119	Indian Point 3	714	102
Quad Cities 2	815	113	Seabrook 1	486	69
Zion 1	858	122	Seabrook 2	320	46
Zion 2	824	117	Salem 1	791	113
LaSalle 1	572	79	Salem 2	764	109
LaSalle 2	572	79	Hope Creek 1	509	71
Byron 1	638	88	Ginna	503	71
Byron 2	631	86	Rancho Seco 1	721	103
Braidwood 1	568	83	Summer	12	2
Connecticut Yankee	702	100	San Onofre 1	203	29
Indian Point 1	80	11	San Onofre 2	306	44
Indian Point 2	762	108	San Onofre 3	347	50
Big Rock Point	104	14	South Texas Project 1	594	82
Palisades	796	113	South Texas Project 2	592	82
Midland 2	373	49	Browns Ferry 1	699	135
Midland 1	334	46	Browns Ferry 2	695	140
La Crosse	143	19	Browns Ferry 3	986	137
Fermi 2	609	85	Sequoyah 1	444	46
Oconee 1	759	108	Sequoyah 2	425	42
Oconee 2	612	87	Watts Bar 1	518	74
Oconee 3	779	111	Watts Bar 2	524	74
McGuire 1	115	17	Bellefonte 1	444	64
McGuire 2	73	11	Bellefonte 2	327	47
Beaver Valley 1	735	104	Hartsville A1	463	65
Beaver Valley 2	272	39	Hartsville A2	328	45
Crystal River 3	676	96	Yellow Creek 1	90	13
Turkey Point 3	695	99	Yellow Creek 2	50	8
Turkey Point 4	694	99	Comanche Peak 1	412	58
St. Lucie 1	894	113	Comanche Peak 2	368	53
St. Lucie 2	486	70	Davis-Besse 1	248	31
Hatch 1	312	43	Callaway 1	360	51
Hatch 2	289	40	Vermont Yankee	675	93
Vogtle 1	547	78	Surry 1	748	102
Vogtle 2	416	60	Surry 2	620	77
River Bend 1	465	65	North Anna 1	365	47
Clinton 1	528	74	North Anna 2	295	38
Cook 1	948	135	WNP 2	650	90
Cook 2	933	133	WNP 1	394	56
Duane Arnold	562	79	WNP 3	617	89
Oyster Creek	777	108	Point Beach 1	620	88
Wolf Creek	191	27	Point Beach 2	591	84
Shoreham	270	38	Kewaunee	634	90
Waterford 3	421	61	Yankee	340	48
Maine Yankee	980	140	Brunswick 2	72	10
Three Mile Island 1	723	103	Brunswick 1	80	11
Grand Gulf 1	247	35	Morris BWR pool	150	20
Grand Gulf 2	340	48	Morris PWR pool	175	25
Cooper	771	107	West Valley BWR pool	17	2
Nine Mile Point 1	700	97	West Valley PWR pool	60	8
Nine Mile Point 2	243	33			
				70,553	9,927

Table A-19. Number of shipments to an MRS facility from eastern and western reactors

Reactor name	100% by Truck	100% by Rail	Reactor name	100% by Truck	100% by Rail
Farley 1	387	56	Humboldt Bay ^a	86	12
Farley 2	513	45	Diablo Canyon 2 ^a	209	30
Palo Verde 1 ^a	366	52	Diablo Canyon 1 ^a	252	36
Palo Verde 2 ^a	339	49	Susquehanna 1	516	71
Palo Verde 3 ^a	332	47	Susquehanna 2	483	67
Arkansas Nuclear One 1	762	108	Peach Bottom 2	1,126	156
Arkansas Nuclear One 2	495	43	Peach Bottom 3	1,126	156
Calvert Cliffs 1	893	127	Limerick 1	500	70
Calvert Cliffs 2	853	121	Limerick 2	287	40
Pilgrim 1	761	105	Trojan ^a	805	117
Robinson 2	581	83	Fitzpatrick	864	127
Brunswick 2	799	111	Indian Point 3	714	102
Brunswick 1	791	109	Seabrook 1	343	49
Harris 1	160	23	Seabrook 2	177	26
Perry 1	722	100	Salem 1	791	113
Perry 2	579	80	Salem 2	764	109
Dresden 1	136	18	Hope Creek 1	365	51
Dresden 2	909	126	Ginna	503	71
Dresden 3	825	114	Rancho Seco 1 ^a	721	103
Quad-Cities 1	862	119	Summer	215	31
Quad-Cities 2	815	113	San Onofre 1 ^a	203	29
Zion 1	858	122	San Onofre 2 ^a	306	44
Zion 2	824	117	San Onofre 3 ^a	348	49
LaSalle 1	669	93	South Texas Project 1	539	77
LaSalle 2	632	87	South Texas Project 2	453	64
Byron 1	593	85	Browns Ferry 1	944	135
Byron 2	552	78	Browns Ferry 2	821	140
Braidwood 1	570	81	Browns Ferry 3	986	137
Braidwood 2	484	69	Sequoyah 1	588	113
Connecticut Yankee	702	100	Sequoyah 2	571	108
Indian Point 1	80	11	Watts Bar 1	465	66
Indian Point 2	762	108	Watts Bar 2	424	61
Big Rock Point	104	14	Bellefonte 1	315	45
Palisades	796	113	Bellefonte 2	199	29
Midland 2	304	43	Hartsville A1	284	40
Midland 1	261	37	Hartsville A2	194	26
La Crosse	143	19	Comanche Peak 1	294	42
Fermi 2	609	85	Comanche Peak 2	257	33
Oconee 1	759	108	Davis Besse 1	321	43
Oconee 2	612	87	Callaway 1	260	38
Oconee 3	779	111	Vermont Yankee	675	93
McGuire 1	334	44	Surry 1	748	106
McGuire 2	268	39	Surry 2	620	88
Catawba 1	241	31	North Anna 1	469	58
Catawba 2	198	25	North Anna 2	420	50
Beaver Valley 1	735	105	WNP 2 ^a	605	84
Beaver Valley 2	154	22	WNP 1 ^a	251	36
Crystal River 3	676	96	WNP 3 ^a	448	63
Turkey Point 3	695	99	Point Beach 1	620	88
Turkey Point 4	694	99	Point Beach 2	591	84
St. Lucie 1	914	130	Kewaunee	634	90
St. Lucie 2	375	54	Yankee	340	48
Hatch 1	512	61	Brunswick 2	72	10
Hatch 2	482	57	Brunswick 1	80	11
Vogtle 1	415	59	Shoreham	201	28
Vogtle 2	290	41	Waterford 3	291	42
River Bend 1	329	45	Maine Yankee	980	140
Clinton 1	407	57	Three Mile Island	723	103
Cook 1	948	135	Grand Gulf 1	318	45
Cook 2	933	133	Grand Gulf 2	210	30
Arnold	572	79	Cooper	771	107
Oyster Creek	777	108	Nine Mile Point 1	700	97
Wood Creek	184	27	Nine Mile Point 2	185	26

Table A-19. Number of shipments to an MRS facility from eastern and western reactors

Reactor name	100% by Truck	100% by Rail	Reactor name	100% by Truck	100% by Rail
Millstone 1	804	111	Fort Calhoun 1	534	76
Millstone 2	949	135	Morris BWR pool	150	20
Millstone 3	227	33	Morris PWR pool	175	25
Monticello	693	96	West Valley BWR pool	17	2
Prairie Island 1	650	92	West Valley PWR pool	<u>60</u>	<u>8</u>
Prairie Island 2	631	90			
			Total	70,568	9,934

^a Considered a western reactor for this analysis.

Table A-20a. Number of cask shipments: total cask-shipments from reactors

Destination	Mode	Number of cask shipments		
		PWR	BWR	Total
Repository	100 % truck	43,611	26,942	70,553
	100 % rail	6,190	3,737	9,927
MRS facility, all spent fuel	100 % Truck	44,222	26,346	70,568
	100 % Rail	6,267	3,667	9,934
MRS facility, eastern spent fuel only	100 % Truck	40,915	24,382	65,297
	100 % Rail	5,793	3,390	9,183

Table A-20b. Number of cask-shipments: total cask shipments of consolidated spent fuel from MRS facility^a

Destination (repository site)	Cask size (tons)	All spent fuel	Eastern fuel only
Salt sites ^b	100	8,074	7,500
	150	2,103	1,900
Tuff	100	8,050	7,500
	150	3,186	3,000
Basalt	100	6,610	6,100
	150	1,823	1,700

^a Estimates of shipment numbers.

^b Richton, Deaf Smith, or Davis Canyon.

Table A-21. Summary of the risks of transporting spent fuel and high-level wastes for disposal in the authorized system^a

Mode and risk type	Salt			Tuff (Yucca Mt)	Basalt (Hanford)
	Richton	Deaf Smith	Davis Canyon		
100% truck					
Radiological	6.3	7.9	9.5	11	12
Nonradiological	19	24	30	36	39
100% rail					
Radiological	0.2	0.2	0.3	0.3	0.3
Nonradiological	1.8	2.1	2.6	3.0	3.2

^a Risks expressed in numbers of fatalities from radiological and nonradiological causes. The numbers of fatalities from radiological causes include first- and second-generation genetic effects.

Table A-22. Summary of the risks of transportation
for the improved-performance system^{a, b}

Mode and risk type	Richton	Deaf Smith	Davis Canyon	Yucca Mt.	Hanford
100% Truck, 100-ton cask ^{c, d}					
Radiological	5.3	5.4	5.4	5.7	5.7
Nonradiological	21	30	35	42	39
100% rail, 100-ton cask ^{d, e}					
Radiological	0.2	0.3	0.3	0.3	0.3
Nonradiological	6.9	16	22	27	24
100% truck, 150-ton cask ^{c, f}					
Radiological	5.3	5.3	5.4	5.7	5.7
Nonradiological	17	19	21	27	23
100% rail, 150-ton cask ^{e, f}					
Radiological	0.2	0.2	0.2	0.3	0.2
Nonradiological	3.0	5.4	6.9	12	7.8

^a All spent fuel assumed to be sent first to the MRS facility and from there to the repository; all high-level waste assumed to be sent directly to the repository.

^b Risks expressed in numbers of fatalities from radiological and nonradiological causes. The numbers of radiological fatalities include first- and second-generation genetic effects.

^c Shipment by truck from reactors and HLW processing plants; shipment in dedicated trains from MRS facility to repository.

^d Shipment in general-commerce trains from reactors and HLW processing plants; shipment in dedicated trains from MRS facility.

^e The 100-ton cask carries ready-to-emplac disposal containers.

^f The 150-ton cask carries thin-walled canisters to be encapsulated in disposal containers at the repository.

Table A-23. Summary of the risks of transporting for disposal in the improved-performance system^{a,b}

Mode and risk type	Salt			Tuff (Yucca Mt.)	Basalt (Hanford)
	Richton	Deaf Smith	Davis Canyon		
100% truck, 100-ton cask ^{c,d}					
Radiological	5.4	5.0	5.0	5.3	5.3
Nonradiological	20	28	32	39	35
100% rail, 100-ton cask ^{d,e}					
Radiological	0.2	0.2	0.3	0.3	0.3
Nonradiological	6.5	15	20	25	22
100% truck, 150-ton cask ^{c,f}					
Radiological	5.3	5.0	5.0	5.2	5.2
Nonradiological	17	18	19	24	21
100% rail, 150-ton cask ^{d,f}					
Radiological	0.2	0.2	0.2	0.3	0.2
Nonradiological	2.8	5.0	6.4	11	7.3

^a Spent fuel from eastern reactors assumed to be sent first to the MRS facility and from there to the repository; spent fuel from western reactors assumed to be sent directly to the repository. All high-level waste assumed to be sent directly to the repository.

^b Risks expressed in numbers of fatalities from radiological and nonradiological causes. The numbers of radiological fatalities include first- and second-generation genetic effects.

^c Shipment by truck from reactors and HLW processing plants; shipment in dedicated trains from MRS facility to repository.

^d Shipment in general-commerce trains from reactors and HLW processing plants, shipment in dedicated trains from MRS facility.

^e The 100-ton cask carries ready-to-emplace disposal containers.

^f The 150-ton cask carries thin-walled canisters to be encapsulated in disposal containers at the repository.

Table A-24. Transportation risks for authorized system from spent fuel only

Mode and risk type	Salt			Tuff (Yucca Mt.)	Basalt (Hanford)
	Richton	Deaf Smith	Davis Canyon		
RADIOLOGICAL RISK ^a					
Truck transportation					
Normal occupational fatalities	0.7	1.0	1.2	1.4	1.6
Normal nonoccupational fatalities	3.8	5.2	6.5	7.7	8.4
Accident nonoccupational fatalities	<u>0.02</u>	<u>0.03</u>	<u>0.03</u>	<u>0.04</u>	<u>0.04</u>
Total fatalities	4.6	6.2	7.7	9.2	10
Rail transportation					
Normal occupational fatalities	0.06	0.07	0.09	0.1	0.1
Normal nonoccupational fatalities	0.08	0.08	0.1	0.1	0.1
Accident nonoccupational fatalities	<u>0.02</u>	<u>0.02</u>	<u>0.02</u>	<u>0.02</u>	<u>0.02</u>
Total fatalities	0.2	0.2	0.2	0.2	0.2
NONRADIOLOGICAL RISK					
Truck transportation					
Normal nonoccupational fatalities	0.2	0.2	0.4	0.4	0.4
Accident occupational fatalities	2.7	3.9	5.2	6.4	6.8
Accident nonoccupational fatalities	9.6	14	18	23	24
Accident occupational injuries	5.5	7.7	10	12	13
Accident nonoccupational injuries	<u>160</u>	<u>220</u>	<u>290</u>	<u>370</u>	<u>380</u>
Total fatalities	13	18	24	29	31
Rail transportation					
Normal nonoccupational fatalities	0.1	0.1	0.1	0.2	0.2
Accident occupational fatalities	0.07	0.09	0.1	0.1	0.1
Accident nonoccupational fatalities	.1	1.3	1.7	2.1	2.1
Accident occupational injuries	9.2	12	15	19	19
Accident nonoccupational injuries	<u>1.9</u>	<u>2.4</u>	<u>3.2</u>	<u>4.0</u>	<u>4.0</u>
Total fatalities	1.2	1.5	1.9	2.4	2.4

^a Radiological fatalities include first- and second-generation genetic effects.

Table A-25. Transportation risks for the authorized system from high-level waste only

Mode and risk type	Salt			Tuff (Yucca Mt.)	Basalt (Hanford)
	Richton	Deaf Smith	Davis Canyon		
RADIOLOGICAL RISK ^a					
Truck transportation					
Normal occupational fatalities	0.3	0.3	0.3	0.3	0.3
Normal nonoccupational fatalities	1.5	1.5	1.5	1.8	1.8
Accident nonoccupational fatalities	<u>0.001</u>	<u>0.001</u>	<u>0.001</u>	<u>0.001</u>	<u>0.001</u>
Total fatalities	1.8	1.8	1.8	2.1	2.1
Rail transportation					
Normal occupational fatalities	0.03	0.03	0.03	0.04	0.04
Normal nonoccupational fatalities	0.03	0.03	0.03	0.04	0.04
Accident nonoccupational fatalities	<u>0.0011</u>	<u>0.001</u>	<u>0.001</u>	<u>0.002</u>	<u>0.001</u>
Total fatalities	0.6	0.06	0.07	0.08	0.08
NONRADIOLOGICAL RISK					
Truck transportation					
Normal occupational fatalities	0.02	0.1	0.05	0.1	0.02
Accident occupational fatalities	1.4	1.3	1.3	1.6	1.6
Accident nonoccupational fatalities	4.8	4.7	4.7	5.7	5.8
Accident occupational injuries	2.7	2.6	2.6	3.1	3.2
Accident nonoccupational injuries	<u>76</u>	<u>75</u>	<u>75</u>	<u>90</u>	<u>91</u>
Total fatalities	6.2	6.2	6.1	7.4	7.4
Rail transportation					
Normal occupational fatalities	0.03	0.04	0.04	0.04	0.04
Accident occupational fatalities	0.04	0.04	0.04	0.04	0.05
Accident nonoccupational fatalities	0.6	0.6	0.6	0.6	0.7
Accident occupational injuries	5.3	5.3	5.4	5.3	6.6
Accident nonoccupational injuries	<u>1.1</u>	<u>1.1</u>	<u>1.1</u>	<u>1.1</u>	<u>1.4</u>
Total fatalities	0.6	0.6	0.7	0.6	0.8

^a Radiological fatalities include first- and second-generation genetic effects.

Table A-26. Total transportation risks for the authorized system

Mode and risk type	Salt			Tuff (Yucca Mt.)	Basalt (Hanford)
	Richton	Deaf Smith	Davis Canyon		
RADIOLOGICAL RISK ^a					
Truck transportation.					
Normal occupational fatalities	1	1.3	1.5	1.7	1.9
Normal nonoccupational fatalities	5.3	6.6	8.0	9.5	10
Accident nonoccupational fatalities	<u>0.03</u>	<u>0.03</u>	<u>0.03</u>	<u>0.04</u>	<u>0.04</u>
Total fatalities	6.3	7.9	9.5	11	12
Rail transportation					
Normal occupational fatalities	0.1	0.1	0.1	0.1	0.1
Normal nonoccupational fatalities	0.1	0.1	0.1	0.1	0.2
Accident nonoccupational fatalities	<u>0.02</u>	<u>0.02</u>	<u>0.02</u>	<u>0.02</u>	<u>0.02</u>
Total fatalities	0.2	0.2	0.3	0.3	0.3
NONRADIOLOGICAL RISK					
Truck transportation					
Normal nonoccupational fatalities	0.2	0.3	0.4	0.6	0.4
Accident occupational fatalities	4.1	5.2	6.5	8	8.4
Accident nonoccupational fatalities	14	18	23	28	30
Accident occupational injuries	8.1	10	13	16	17
Accident nonoccupational injuries	<u>230</u>	<u>300</u>	<u>370</u>	<u>450</u>	<u>470</u>
Total fatalities	19	24	30	37	39
Rail transportation					
Normal nonoccupational fatalities	0.2	0.2	0.2	0.2	0.2
Accident occupational fatalities	0.1	0.1	0.2	0.2	0.2
Accident nonoccupational fatalities	1.5	1.8	2.2	2.6	2.8
Accident occupational injuries	14	17	21	25	26
Accident nonoccupational injuries	<u>3</u>	<u>3.5</u>	<u>4.3</u>	<u>5.1</u>	<u>5.4</u>
Total fatalities	1.8	2.1	2.6	3.0	3.2

^a Radiological fatalities include first- and second-generation genetic effects.

Table A-27. Transportation risks for the improved-performance system from shipping spent fuel from reactors to the MRS facility^a

Mode and risk type	Salt			Tuff (Yucca Mt.)	Basalt (Hanford)
	Richton	Deaf Smith	Davis Canyon		
RADIOLOGICAL RISK ^b					
Truck transportation					
Normal occupational fatalities	0.6	0.6	0.6	0.6	0.6
Normal nonoccupational fatalities	3	3	3	3	3
Accident nonoccupational fatalities	<u>0.02</u>	<u>0.02</u>	<u>0.02</u>	<u>0.02</u>	<u>0.02</u>
Total fatalities	3.6	3.6	3.6	3.6	3.6
Rail transportation					
Normal occupational fatalities	0.05	0.05	0.05	0.05	0.05
Normal nonoccupational fatalities	<u>0.07</u>	<u>0.07</u>	<u>0.07</u>	<u>0.07</u>	<u>0.07</u>
Accident nonoccupational fatalities	<u>0.02</u>	<u>0.02</u>	<u>0.02</u>	<u>0.02</u>	<u>0.02</u>
Total fatalities	0.1	0.1	0.1	0.1	0.1
NONRADIOLOGICAL RISK					
Truck transportation					
Normal nonoccupational fatalities	0.2	0.2	0.2	0.2	0.2
Accident occupational fatalities	2	2	2	2	2
Accident nonoccupational fatalities	7	7	7	7	7
Accident occupational injuries	4.1	4.1	4.1	4.1	4.1
Accident nonoccupational injuries	<u>120</u>	<u>120</u>	<u>120</u>	<u>120</u>	<u>120</u>
Total fatalities	9.1	9.1	9.1	9.1	9.1
Rail transportation					
Normal nonoccupational fatalities	0.1	0.1	0.1	0.1	0.1
Accident occupational fatalities	0.05	0.05	0.05	0.05	0.05
Accident nonoccupational fatalities	0.8	0.8	0.8	0.8	0.8
Accident occupational injuries	7	7	7	7	7
Accident nonoccupational injuries	<u>1.4</u>	<u>1.4</u>	<u>1.4</u>	<u>1.4</u>	<u>1.4</u>
Total fatalities	0.9	0.9	0.9	0.9	0.9

^a Estimated risks of shipping all spent fuel from reactors to the MRS facility. The risks are the same for all four of the scenarios discussed in the text.

^b Radiological fatalities include first- and second-generation genetic effects.

Table A-28. Transportation risks for the improved-performance system from shipping consolidated spent fuel from the MRS facility to the repository^a

Risk type	Salt			Tuff (Yucca Mt.)	Basalt (Hanford)
	Richton	Deaf Smith	Davis Canyon		
RADIOLOGICAL RISK ^b					
Normal occupational fatalities	0.002	0.004	0.005	0.006	0.005
Normal nonoccupational fatalities	0.02	0.02	0.02	0.03	0.03
Accident nonoccupational fatalities	<u>0.006</u>	<u>0.01</u>	<u>0.01</u>	<u>0.01</u>	<u>0.01</u>
Total fatalities	0.02	0.04	0.04	0.05	0.04
NONRADIOLOGICAL RISK					
Normal nonoccupational fatalities	0.01	0.09	0.1	0.1	0.07
Accident occupational fatalities	0.3	0.9	1.3	1.6	1.4
Accident nonoccupational fatalities	5	14	19	24	21
Accident occupational injuries	47	130	180	220	190
Accident nonoccupational injuries	<u>9.7</u>	<u>26</u>	<u>36</u>	<u>46</u>	<u>40</u>
Total fatalities	5.4	15	20	25	22

^a Estimated risks from shipping consolidated spent fuel from the MRS facility to the repository. All shipments assumed to be by dedicated train in 100-ton casks carrying ready-to-emplac disposal containers.

^b Radiological fatalities include first- and second-generation genetic effects.

Table A-29. Transportation risks for the improved-performance system from shipping secondary waste from the MRS facility to the repository^a

Type of risk	Salt			Tuff (Yucca Mt.)	Basalt (Hanford)
	Richton	Deaf Smith	Davis Canyon		
RADIOLOGICAL RISK ^b					
Normal occupational fatalities	0.0008	0.001	0.002	0.002	0.002
Normal nonoccupational fatalities	0.005	0.008	0.009	0.01	0.014
Accident nonoccupational fatalities	<u>0.006</u>	<u>0.01</u>	<u>0.01</u>	<u>0.02</u>	<u>0.02</u>
Total fatalities	0.008	0.02	0.02	0.03	0.02
NONRADIOLOGICAL RISK					
Normal nonoccupational fatalities	0.008	0.02	0.03	0.04	0.03
Accident occupational fatalities					
Accident nonoccupational fatalities					
Accident occupational injuries					
Accident nonoccupational injuries	<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u> </u>
Total fatalities	0.008	0.02	0.03	0.04	0.03

^a Estimated risks of shipping secondary waste (spent-fuel-assembly hardware, high-activity low-level waste, and contact-handled transuranic waste) from the MRS facility to the repository. All secondary-waste shipments assumed to be by dedicated train in 100-ton casks.

^b Radiological fatalities include first- and second-generation genetic effects.

Table A-30. Transportation risks for the improved-performance system from shipping high-level waste to the repository^a

Mode and risk type	Salt			Tuff (Yucca Mt.)	Basalt (Hanford)
	Richton	Deaf Smith	Davis Canyon		
RADIOLOGICAL RISK ^b					
Truck transportation					
Normal occupational fatalities	0.3	0.3	0.3	0.3	0.3
Normal nonoccupational fatalities	1.5	1.5	1.5	1.8	1.8
Accident nonoccupational fatalities	<u>0.001</u>	<u>0.001</u>	<u>0.001</u>	<u>0.001</u>	<u>0.001</u>
Total fatalities	1.8	1.8	1.8	2.1	2.1
Rail transportation					
Normal occupational fatalities	0.03	0.03	0.03	0.04	0.04
Normal nonoccupational fatalities	0.03	0.03	0.03	0.04	0.04
Accident nonoccupational fatalities	<u>0.001</u>	<u>0.001</u>	<u>0.001</u>	<u>0.002</u>	<u>0.001</u>
Total fatalities	0.06	0.06	0.07	0.08	0.07
NONRADIOLOGICAL RISK					
Truck transportation					
Normal nonoccupational fatalities	0.02	0.1	0.05	0.1	0.02
Accident occupational fatalities	1.4	1.3	1.3	1.6	1.6
Accident nonoccupational fatalities	4.8	4.7	4.7	5.7	5.8
Accident occupational injuries	2.7	2.6	2.6	3.1	3.2
Accident nonoccupational injuries	<u>76</u>	<u>75</u>	<u>75</u>	<u>90</u>	<u>91</u>
Total fatalities	6.2	6.2	6.2	7.4	7.4
Rail transportation					
Normal nonoccupational fatalities	0.03	0.04	0.04	0.06	0.04
Accident occupational fatalities	0.04	0.04	0.04	0.05	0.05
Accident nonoccupational fatalities	0.6	0.6	0.6	0.7	0.7
Accident occupational injuries	5.3	5.3	5.4	6.9	6.6
Accident nonoccupational injuries	<u>1.4</u>	<u>1.1</u>	<u>1.1</u>	<u>1.4</u>	<u>1.4</u>
Total fatalities	0.63	0.64	0.66	0.84	0.79

^a Estimated risk of shipping high-level waste directly to the repository. All shipments assumed to be in 100-ton casks.

^b Radiological fatalities include first- and second-generation genetic effects.

Table A-31. Total transportation risks for the improved-performance system^a

Mode and risk type	Salt			Tuff (Yucca Mt.)	Basalt (Hanford)
	Richton	Deaf Smith	Davis Canyon		
RADIOLOGICAL RISK ^b					
Truck transportation ^c					
Normal occupational fatalities	0.9	0.8	0.9	0.9	0.9
Normal nonoccupational fatalities	4.5	4.4	4.5	4.7	4.8
Accident nonoccupational fatalities	<u>0.03</u>	<u>0.05</u>	<u>0.05</u>	<u>0.06</u>	<u>0.05</u>
Total fatalities	5.3	5.4	5.4	5.7	5.7
Rail transportation ^d					
Normal occupational fatalities	0.09	0.09	0.09	0.1	0.1
Normal nonoccupational fatalities	0.1	0.1	0.1	0.1	0.1
Accident nonoccupational fatalities	<u>0.03</u>	<u>0.04</u>	<u>0.04</u>	<u>0.05</u>	<u>0.04</u>
Total fatalities	0.2	0.3	0.3	0.3	0.3
NONRADIOLOGICAL RISK					
Truck transportation ^c					
Normal nonoccupational fatalities	0.2	0.4	0.4	0.5	0.3
Accident occupational fatalities	3.7	4.3	4.6	5.2	5.0
Accident nonoccupational fatalities	17	25	30	36	33
Accident occupational injuries	54	130	180	230	200
Accident nonoccupational injuries	<u>200</u>	<u>220</u>	<u>230</u>	<u>250</u>	<u>250</u>
Total fatalities	21	30	35	42	39
Rail transportation ^d					
Normal nonoccupational fatalities	0.2	0.3	0.3	0.4	0.3
Accident occupational fatalities	0.4	1.0	1.4	1.7	1.5
Accident nonoccupational fatalities	6.3	15	20	25	22
Accident occupational injuries	59	140	190	240	210
Accident nonoccupational injuries	<u>12</u>	<u>25</u>	<u>39</u>	<u>49</u>	<u>43</u>
Total fatalities	6.9	16	22	27	24

^a Estimated risks of shipping (1) all spent fuel from reactors to the MRS facility, (2) consolidated spent fuel from the MRS facility to the repository, (3) secondary waste from the MRS facility to the repository, and (4) high-level waste directly to the repository. All shipments from the MRS facility assumed to be in 100-ton casks.

^b Radiological fatalities include first- and second-generation genetic effects.

^c Shipment by truck from reactors and HLW processing plants; shipment in dedicated trains from MRS facility to repository.

^d The 100-ton cask carries ready-to-emplace disposal containers.

A.8.3.9 Uncertainties

The results presented here are to be used only in comparing potential repository sites, because their absolute values, though considered to be representative, have acknowledged uncertainties associated with them. Important ones include the following:

1. The risk analysis (Section A.8.2.8) was performed on a national scale, using aggregate input from large regions. As a result, these inputs are averaged and may not accurately reflect information for a specific route.
2. The packaging capacities are not known at this time nor are actual exposure rates for new casks.
3. Some inputs will be refined during the studies conducted concurrently with site characterization and during the preparation of the environmental impact statement.

A.9 COST ANALYSIS

Early efforts at defining the transportation-system equipment and operating requirements for the repository were initiated in the late 1970s, when it was recognized that transportation is an important factor in repository siting. This section summarizes the method, assumptions, and models used in analyzing the costs of waste transportation.

A.9.1 OUTLINE OF METHOD

The analysis in this environmental assessment makes use of the models developed to evaluate the costs of transporting waste to a repository. The analysis is dependent on a logistics code, WASTES, which analyzes the cost of transport and hardware requirements (Shay et al., 1985). The hardware costs, both maintenance and capital, are evaluated by using the output from WASTES. The total costs can therefore be thought of as the composite value of shipping costs, hardware capital expenditures, and maintenance allowances. All three factors are highly dependent on the assumptions underlying the analysis.

A.9.2 ASSUMPTIONS

In calculating costs, the spent-fuel discharge data published in a recent DOE report (Heeb et al., 1985) were used. In all scenarios a total of 62,000 MTU of spent fuel is shipped from individual reactor sites. The specific amounts of spent fuel to be shipped from each reactor site were selected on a yearly basis by applying the following criteria:

1. Reactors experiencing a loss of full-core-reserve (FCR) capacity within a given year were given the highest priority.
2. Reactors undergoing decommissioning were given the next highest priority 2 years after their last year of operation.
3. The oldest fuel remaining at reactors was given final priority.

The other major assumptions used in this analysis are described below (see Cashwell et al., 1985, for details).

A.9.3 MODELS

The WASTES model was used to calculate shipping costs and the size of the cask fleet. This model has been benchmarked against past analyses. A good discussion of the capabilities of WASTES is presented by Shay et al. (1985).

A.9.4 COST ESTIMATES

The costs of transporting waste in the various scenarios are shown in Table A-32. Estimates for the authorized system and two scenarios for the improved-performance system are presented in sufficient detail to show the costs of shipping the various types of waste. Only summary results are presented for the other scenarios, but details are available in the report by Cashwell et al. (1985). The results for the same two scenarios are provided in Tables A-33 and A-34 except that different detail is highlighted. In these tables, the three major cost components are shown for spent-fuel shipments only. The basis for the capital and maintenance costs is given in Tables A-35 and A-36. It should be noted in Table A-35 that the cask-maintenance costs are for 15 years—the assumed life of a cask. Table A-36 estimates the numbers of casks needed over the lifetime of the repository for each of the various scenarios.

The costs of transporting high-level waste are given in Tables A-37 and A-38 for each of the repository sites and for each mode considered.

A.9.5 LIMITATIONS OF RESULTS

The results presented should be used only to compare the potentially acceptable sites. As absolute values, they are limited for several reasons:

1. No attempt was made to escalate costs for inflation. All costs are in constant 1985 dollars.
2. The transportation-distance estimates will be affected by the selected routes.

Table A-32. Total transportation cost
(millions of dollars)

Mode and waste type	Repository Site				
	Richton	Deaf Smith	Davis Canyon	Yucca Mt.	Hanford
AUTHORIZED SYSTEM					
100% Truck					
Spent fuel	722	922	1,080	1,286	1,345
Defense high-level waste	207	195	214	237	254
Commercial high-level waste ^a	7	8	10	15	15
100% Rail					
Spent fuel	699	832	917	1,024	1,055
Defense high-level waste	272	279	278	308	308
Commercial high-level waste ^a	10	10	11	12	12
Totals					
Truck from origin	936	1,127	1,305	1,538	1,615
Rail from origin	982	1,122	1,207	1,345	1,376
IMPROVED-PERFORMANCE SYSTEM					
1. All fuel to the MRS facility					
100% truck from origin					
Spent fuel	600	600	600	600	600
Defense high-level waste	207	195	214	237	254
Commercial high-level waste ^a	7	8	10	15	15
100% rail from origin					
Spent fuel	594	593	593	593	593
Defense high-level waste	272	279	278	308	308
Commercial high-level waste ^a	10	10	11	12	12
Rail from MRS, 100-ton casks					
Spent fuel in disposal containers	421	638	728	800	693
Assembly hardware and high-activity waste	80	124	144	164	173
Contact-handled transuranic waste	8	9	9	10	10
Rail from MRS, 150-ton casks					
Spent fuel in disposal containers	157	212	236	412	248
Assembly hardware and high-activity waste	87	123	140	147	172
Contact-handled transuranic waste	8	9	10	10	11

Table A-32. Total transportation cost (Continued)
(millions of dollars)

Mode and waste type	Repository Location				
	Richton	Deaf Smith	Davis Canyon	Yucca Mt.	Hanford
IMPROVED-PERFORMANCE SYSTEM (Continued)					
1. All fuel to the MRS facility (Continued)					
Total cost, 100-ton casks					
Truck from origin	1,323	1,576	1,709	1,828	1,748
Rail from origin	1,384	1,654	1,767	1,889	1,792
Total cost, 150-ton casks					
Truck from origin	1,065	1,149	1,210	1,422	1,301
Rail from origin	1,127	1,227	1,268	1,483	1,345
2. Western-reactor spent fuel directly to the repository					
Total cost, 100-ton casks					
Truck from origin	1,265	1,439	1,560	1,674	1,562
Rail from origin	1,328	1,537	1,640	1,760	1,628
Total cost, 150-ton casks					
Truck from origin	1,046	1,084	1,126	1,308	1,205
Rail from origin	1,109	1,182	1,206	1,394	1,271

• High-level waste from the West Valley Demonstration Project.

Table A-33. Costs of transportation from reactors to repository
in the authorized system^{a, b}
(millions of dollars)

Repository site	Shipping	Capital	Maintenance	Total
ALL SHIPMENTS BY RAIL				
Richton	390	202	108	699
Deaf Smith	477	232	123	832
Davis Canyon	534	250	134	917
Yucca Mountain	604	275	146	1,024
Hanford	626	280	150	1,055
ALL SHIPMENTS BY TRUCK				
Richton	442	181	99	722
Deaf Smith	595	212	116	922
Davis Canyon	717	235	128	1,080
Yucca Mountain	876	266	145	1,286
Hanford	922	274	149	1,345

^a Spent fuel only.

^b Values have been rounded.

Table A-34. Costs of transportation in the improved-performance system^{a, b}
(millions of dollars)

Repository site	Shipping	Capital	Maintenance	Total
RAIL SHIPMENTS TO AND FROM THE MRS FACILITY				
Richton	598	248	256	1,102
Deaf Smith	799	354	212	1,365
Davis Canyon	895	277	306	1,477
Yucca Mountain	963	379	227	1,569
Hanford	906	354	211	1,471
TRUCK SHIPMENTS TO, AND RAIL SHIPMENTS FROM, THE MRS FACILITY				
Richton	623	236	250	1,108
Deaf Smith	824	342	207	1,372
Davis Canyon	919	265	300	1,485
Yucca Mountain	988	367	222	1,576
Hanford	931	342	206	1,479

^a All spent fuel sent first to the MRS facility and from there to the repository, after consolidation. All shipments in 100-ton casks.

^b Cost estimates do not include high-level waste, and values have been rounded.

Table A-35. Capital and maintenance costs
(millions of 1985 dollars)

Transportation mode	Capital ^a	Maintenance ^b
Reactor to MRS facility		
Truck cask	1.5	0.075
Rail cask	2.5	0.125
MRS facility to repository		
100-ton rail cask	2.5	0.125
150-ton rail cask	2.75	0.125
Rail package for transuranic waste ^c	1.6	0.075
Defense high-level waste ^d		
Truck cask	1.1	0.06
Rail cask	1.8	0.09

^a Capital costs are for each cask and include the cost of trailer or railcar.

^b Maintenance costs are per package-year for the assumed 15-year cask life.

^c Based on two packages per railcar.

^d Includes commercial high-level waste from the West Valley Demonstration Project.

Table A-36. Total requirements for transportation packaging
(Number of casks)

Mode and waste type	Repository site				
	Richton	Deaf Smith	Davis Canyon	Yucca Mt.	Hanford
AUTHORIZED SYSTEM					
100% truck					
Spent fuel	124	145	161	182	188
Defense high-level waste	40	43	48	50	53
Commercial high-level waste	2	2	2	4	4
100% rail					
Spent fuel	81	93	100	110	112
Defense high-level waste	34	36	38	42	44
Commercial high-level waste	2	2	2	2	2
IMPROVED-PERFORMANCE SYSTEM					
1. All spent fuel to the MRS facility					
100% truck from origin					
Spent fuel	106	106	106	106	106
Defense high-level waste	40	44	48	51	56
Commercial high-level waste	2	2	2	4	4
100% rail from origin					
Spent fuel	67	67	67	67	67
Defense high-level waste	34	37	38	42	47
Commercial high-level waste	2	2	2	2	2
Rail from MRS, 100-ton casks					
Spent fuel in disposal containers	55	70	75	80	70
High-activity waste	4	4	4	4	4
Contact-handled TRU waste	2	2	2	2	2
Rail from MRS, 150-ton casks					
Spent fuel in canisters	20	20	20	30	20
High-activity waste	8	8	8	6	10
Contact-handled TRU waste	2	2	2	2	2
2. Western-reactor spent fuel to the repository					
100% Truck from origin					
Spent fuel	111	108	106	105	106
Defense high-level waste	40	44	48	51	56
Commercial high-level waste	2	2	2	4	4
100% rail from origin					
Spent fuel	70	69	67	67	67
Defense high-level waste	34	37	38	42	47
Commercial high-level waste	2	2	2	2	2
Rail from MRS, 100-ton casks					
Spent fuel in disposal canisters	50	60	70	70	60
High-activity waste	4	4	4	4	4
Contact-handled TRU work	2	2	2	2	2
Rail from MRS, 150-ton casks					
Spent fuel in canisters	20	20	20	30	20
High-activity waste	8	8	8	6	8
Contact-handled TRU waste	2	2	2	2	2

Table A-37. Costs of transporting high-level waste by truck^a
(millions of 1985 dollars)

Source and destination	Shipping	Capital	Maintenance	Total
Savannah River Plant				
Hanford	135	48	26	210
Yucca Mountain	110	42	23	175
Deaf Smith	63	31	17	111
Richton	34	22	12	68
Davis Canyon	97	40	22	158
Hanford				
Hanford	NA	NA	NA	NA
Yucca Mountain	10	3	3	16
Deaf Smith	15	4	4	23
Richton	24	6	4	34
Davis Canyon	9	3	3	15
Idaho National Engineering Laboratory				
Hanford	26	10	8	44
Yucca Mountain	29	10	8	47
Deaf Smith	40	12	10	62
Richton	74	16	14	105
Davis Canyon	23	10	8	41
West Valley Demonstration Plant ^b				
Hanford	9	4	2	15
Yucca Mountain	8	4	2	15
Deaf Smith	5	2	1	9
Richton	4	2	1	7
Davis Canyon	7	2	1	10

^a Values have been rounded.

^b Commercial high-level waste.

Table A-38. Costs of transporting high-level waste by rail^a
(Millions of 1985 dollars)

Source and destination	Shipping	Capital	Maintenance	Total
SRP to				
Hanford	142	65	32	240
Yucca Mountain	126	54	27	208
Deaf Smith	92	43	22	157
Richton	56	32	16	105
Davis	118	50	25	193
Hanford to				
Hanford	NA	NA	NA	NA
Yucca Mountain	15	5	4	25
Deaf Smith	20	5	4	30
Richton	26	7	5	39
Davis	14	5	4	24
INEL to				
Hanford	44	14	11	69
Yucca Mountain	48	16	12	77
Deaf Smith	64	16	12	92
Richton	91	22	16	129
Davis	39	13	10	61
West Valley to				
Hanford	7	4	2	12
Yucca Mountain	7	4	2	12
Deaf Smith	5	3.6	2	10
Richton	4	4	2	10
Davis	6	4	2	11

^a Values have been rounded.

3. Published tariffs were used in this analysis where available; however, under the deregulation that has recently occurred, the DOE will be able to negotiate with carriers for rates and services, and shipping costs may change.

A.10 BARGE TRANSPORTATION TO REPOSITORIES

The most likely way in which barge transportation would be used to make shipments to a repository would be to complete a partial leg of the journey. In all cases, barges cannot be loaded directly from the reactor-pool loading area without the use of heavy-haul truck equipment or a railcar. In the barge scenario for eastern reactors evaluated by Tobin and Meshkov (1985), it was considered likely that a reactor within 483 kilometers (300 miles) of a large port capable of handling large railcasks and served by a railroad would ship by rail and then use a barge through an intermodal transfer. The eastern reactors for which barge transport was considered to be a feasible option are listed in Table A-39. The shipment from the reactor would then proceed as far as possible by barge, and then another intermodal transfer would occur back to a railroad. This transfer point was assumed to be either in the Gulf of Mexico or on the Mississippi River. Therefore, the shipment would arrive at the repository by railcar. The possible exception where barge loadings and unloadings could be made directly would be a specially designed cask-handling facility at the MRS facility. Because a barge has tremendous capacity (equivalent to at least four rail casks), it is highly inefficient to use small truck casks.

The results given in Table A-40 for the risk from barge transportation generally show that barge transportation increases occupational exposure for normal operations during the shipment of spent fuel. Because barge shipments require intermodal transfer at both ends of the journey, the workers involved in this activity receive relatively high radiation doses and account for the large increase in occupational exposure over the rail mode. The exposure of the public is also increased by the intermodal transfers.

The results presented in Table A-40 are a first attempt at characterizing barge transportation. The numbers are expected to be refined as further studies are conducted to provide models of similar detail as those available for the truck and rail modes. As in previous studies for truck and rail modes, when data are not well characterized, assumptions are made that tend to overpredict the actual values. However, reactor-specific results presented by Tobin and Meshkov (1985) suggest that under several circumstances the barge mode may reduce risk.

Tobin and Meshkov did not investigate the consequences of barge accidents because a previous study (Unione et al., 1978) was found to contain analyses for barge accidents that were similar to those used by Sandquist et al. (1985) for truck and rail accidents. The results of that study are shown in Tables A-41 and A-42. These results can be compared with the equivalent categories in Table A-5. Table A-42 is comparable to results for water release. The results show accidents from barges to be of the same order as for other modes.

Table A-39. Reactor sites included in barge study

Direct to water ^a				Rail to water ^b	
Transfer at Houston ^c		Transfer at Memphis ^d		Transfer at Houston	
Plant	State	Plant	State	Plant	State
Brunswick	North Carolina	Big Rock Point	Michigan	Hatch	Georgia
Calvert Cliffs	Maryland	Browns Ferry	Alabama	McGuire	North Carolina
Crystal River	Florida	Cook	Michigan	North Anna	Virginia
Farley	Alabama	Davis-Besse	Ohio	Peach Bottom	Pennsylvania
Indian Point	New York	Dresden	Illinois	Robinson	South Carolina
Maine Yankee	Maine	Fitzpatrick	New York	Summer	South Carolina
Millstone	Connecticut	GINNA	New York	Susquehanna	Pennsylvania
Oyster Creek	New Jersey	Kewaunee	Wisconsin	Three Mile Island	Pennsylvania
Pilgrim	Massachusetts	Nine Mile Point	New York	Vermont Yankee	Vermont
Salem	New Jersey	Palisades	Michigan		
St. Lucie	Florida	Point Beach	Wisconsin		
Surry	Virginia	Sequoyah	Tennessee		
Turkey Point	Florida	Zion	Illinois		

^a Plants located on a waterway.

^b Plants located within 300 miles of port.

^c Shipments to Houston are by ocean.

^d Shipments to Memphis are by inland waterway.

Table A-40. Projected latent cancers for shipments to repositories
from reactors with barge access^{a, b}

Type of transfer	Deaf Smith		Yucca Mountain		Hanford	
	Barge/rail	All rail	Barge/rail	All rail	Barge/rail	All rail
Offshore to Gulf of Mexico						
Nonoccupational	0.03	0.02	0.04	0.03	0.05	0.03
Occupational	0.09	0.014	0.1	0.02	0.1	0.02
Inland waterways to Mississippi River						
Nonoccupational	0.02	0.01	0.03	0.02	0.03	0.015
Occupational	0.08	0.01	0.08	0.015	0.08	0.015
Rail to water and Gulf of Mexico						
Nonoccupational	0.05	0.01	0.06	0.01	0.06	0.01
Occupational	0.05	0.007	0.06	0.01	0.06	0.01
Total, 35 reactor sites						
Nonoccupational	0.10	0.04	0.13	0.05	0.14	0.06
Occupational	<u>0.22</u>	<u>0.03</u>	<u>0.24</u>	<u>0.05</u>	<u>0.24</u>	<u>0.05</u>
Total	0.32	0.07	0.37	0.10	0.38	0.10

^a Considers shipments from reactors listed in Table A-39 according to schedule given by Tobin and Meshkov (1985).

^b Analysis was made only for three potential repository sites.

Table A-41. Summary of the radiological air-release consequences of airborne releases from barge accidents^a

Accident class ^c	Latent-cancer fatalities ^b	
	Average	Maximum
4	5×10^{-11}	2×10^{-9}
5	6×10^{-6}	2×10^{-4}
6	0.01	0.2

^a Estimates based on data presented by Unione et al. (1978, Table 6.4).

^b Based on the assumption that a population dose of 1 man-rem induces 0.0002 latent-cancer fatality plus first- and second-generation genetic effects.

^c Accident classes from Wilmot et al. (1983).

Table A-42. Summary of the radiological consequences of waterborne releases from barge accidents^a

Specific dose pathway	Latent-cancer fatalities ^b
Drinking water	1.0
Fresh-water fish	4
Shoreline deposits	0.02
Irrigated crops	<u>0.1</u>
Total of all pathways	5

^a Estimates based on data presented by Unione et al. (1978, Table 6.16).

^b Based on the assumption that a population dose of 1 man-rem induces 0.0002 latent-cancer fatality plus first-and second generation genetic effects.

Shipping by barge may be more expensive than the rail mode. Tobin and Meshkov suggest that shipping spent fuel by barge and rail to a repository could cost from \$38 to \$47 per kilogram of uranium, but these numbers are high because new cost estimates for casks are lower than those used in their study. If values from Table A-35 are substituted, the adjusted cost for barge transportation becomes \$27 to \$34 per kilogram of uranium. This compares with a range for rail of \$13 to \$17 per kilogram of uranium, or approximately half the barge and rail cost. The barge-and-rail cost can be reduced by adding more casks to each barge; Tobin and Meshkov assume four railcasks on a barge. It is feasible to ship at least six casks on a barge.

A primary objective of the Tobin and Meshkov study was to determine whether barge transportation is a discriminating factor in site selection. It can be inferred, however, from Table A-40 and from the preliminary estimates of cost per kilogram of uranium shipped that barge transportation will augment the other modes and will be used in special circumstances where the other modes are not available. Since all shipments in the region of the repository site will be completed by rail or truck even if barges are used, no site has a significant advantage because of its proximity to a nearby port. For example, the Richton site may appear to be better than Yucca Mountain because of its proximity to the Gulf of Mexico, but there is no advantage because a shipment to either site must be completed by rail. Similarly, barges on the Columbia River could arrive within about 16 miles of the Hanford site, but this option does not appear reasonable or probable for eastern reactors because of the additional crew exposure, cost, and time required to complete a shipment via the Panama Canal. Administrative concerns, including safeguarding and travel through foreign countries, add to the unlikeliness of this option. As can be seen in Figure A-4, some reactors west of the longitude 100°W could ship to the Hanford site using intermodal transfers. The Trojan plant in Oregon as well as the Humboldt Bay and Diablo Canyon plants in California could possibly ship directly if the proper dock facilities were available. It is not likely that a barge can land at San Onofre in California. Power plants in Arizona and the Rancho Seco plant in California are also not likely to ship by barge because rail shipments would have to be made to a suitable port. In each case, this port is likely to be densely populated, and therefore there is little incentive to use barges.

No additional insight for ranking sites is gained from Table A-40. At this preliminary stage in the evaluation of the barge mode for its feasibility and safety, it is concluded that the barge option is not a discriminating element in comparing sites.

A.11 EFFECT OF THE SECOND REPOSITORY ON TRANSPORTATION ESTIMATES

The analyses that have been discussed to this point (see Section A.8.3) do not explicitly consider the effect of the second repository; however, the siting guideline on transportation requires the second repository to be considered in the cost and risk analyses. A supplementary analysis was performed to predict the expected uncertainty in the results for a single repository when a second repository is added to the waste-management system.

Figure A-4. Reactors west of 100° W longitude.

A.11.1 SINGLE-REPOSITORY ANALYSES

The impacts resulting from shipments from reactors to the repository have been evaluated for both the authorized system and the improved-performance system.

In the authorized system, spent fuel and high-level waste are shipped directly to the repository. The spent fuel that was assumed to be shipped is generally the oldest fuel, except when a reactor that is running out of storage capacity is given preference. The geographic location of the fuel is not considered.

In the scenarios analyzed for the improved-performance system, similar assumptions were made about the fuel that is shipped, but the fuel is sent first to the MRS facility and then to the repository. Four variations of the improved-performance system were considered. The first two assumed that all of the spent fuel that is received by the repository is routed through the MRS facility. These two variations differ only in the size of the cask assumed to be used for shipments from the MRS facility to the repository (100 and 150 tons). Defense high-level waste is sent directly to the repository; it does not pass through the MRS facility.

Two other variations were generated by taking into account the geographic distribution of some of the fuel. In these variations, about 4,500 MTU of spent fuel from the reactors west of the Rockies is sent to the first repository without passing through the MRS facility. The remaining fuel is preferentially selected by age except for cases where reactors have no storage capacity. These two variations are also distinguishable because two different cask sizes were assumed for each.

None of the variations of the improved-performance system or the authorized system fully consider the geographic distribution of fuel; some do not consider it at all.

A.11.2 LOGIC SUPPORTING THE SUPPLEMENTARY ANALYSIS

If a second repository is introduced into the waste-management system, the spent fuel that will be sent to the first repository can be chosen not only for the age of the fuel but also for the proximity of the fuel to the repository. Logic and the mandate of the Act appear to dictate that fuel closest to the first repository should be shipped to it, with the remainder being shipped to the second repository. When an MRS facility is added to the waste-management system, the ideal fuel selection for the first repository would be the fuel farthest from the second repository (approximately nearest the first repository).

The second repository will enter the system several years after the first. Consequently, its effect on the population of reactors shipping to the first repository will be somewhat reduced because the reactors with storage problems would likely not be restricted from shipment to a more distant first repository as long as their storage problems remained. The supplementary analysis more closely represents a system that simultaneously has two

repositories in operation and therefore will manifest the greatest effect of regionality on the transportation impacts.

A.11.3 DESCRIPTION OF SUPPLEMENTARY ANALYSES

Two separate analyses were performed: one that considered the MRS facility and another that did not. For each analysis, two cases were considered: (1) the first repository receives spent fuel from reactors closest to it and (2) the first repository receives spent fuel from reactors farthest from it (Figure A-5). Only Yucca Mountain is shown in Figure A-5; however, similar figures were generated for analyses for each of the five sites nominated as suitable for characterization.

The major assumptions are as follows:

- o The cumulative spent-fuel quantities were assumed to be those of the "midcase" projection by the DOE's Energy Information Administration (EIA).
- o Estimates based on adjusted "great circle" distances.
- o Use of 150-ton casks for shipments from the MRS facility.
- o All spent fuel routed through the MRS facility.
- o Only spent fuel was assumed to be shipped.

The results are presented in Table A-43. Only cask-miles were calculated because cask-miles are a good surrogate measure of transportation costs and risks. Table A-44 contains the percentage variation from the single-repository values. It can be seen that the introduction of a second repository can produce a significant effect on the results for a single-repository analysis.

A.12 CRITERIA FOR APPLYING THE TRANSPORTATION GUIDELINE

The siting guideline on transportation (10 CFR 960.5-2-7) contains a number of terms that are subject to interpretation. These terms are underlined in Table A-45, which is a complete listing of both the favorable and the potentially adverse conditions of the guideline. Terms like "short," "economical," "cuts," and "fills" are clearly open to interpretation. These common terms generally defy the application of accepted objective definitions.

Early in the process of implementing the guideline, it was recognized that a consistent set of criteria was needed to apply the transportation guideline. In September 1984, an ad hoc transportation group was established to deal with transportation issues in the environmental assessments (EAs). The group included a member from the DOE Project Offices representing the three host rocks considered for the first repository and representing substantial expertise in the transportation of radioactive waste. One member had been instrumental in drafting the guideline itself. Before the issuance of the draft EAs, this group developed criteria for applying favorable conditions 1, 2, and 3 and potentially adverse conditions 1 and 3. These

Figure A-5. Analysis of shipping from farthest and closest reactors to Yucca Mountain.

Table A-43. Cask-miles from reactors to potential repository locations
with and without an MRS facility^a
(Millions of cask-miles)

Repository site	Without MRS facility			With MRS facility		
	Closest	EA Analysis	Farthest	Closest	EA Analysis	Farthest
Richton	6.5	11.0	15.3	5.1	9.2	14.0
Deaf Smith	11.6	15.4	18.7	6.8	10.9	15.7
Davis Canyon	14.1	18.8	22.7	7.8	11.9	16.7
Yucca Mountain	17.4	23.2	27.6	11.4	15.6	20.3
Hanford	19.2	24.6	28.9	8.6	12.8	17.5

^a Estimates based on the shipment of 62,000 MTU of spent fuel.

Table A-44. Percent variation in cask-miles resulting from the introduction
of second repository

Repository site	Without MRS facility		With MRS facility	
	Closest	Farthest	Closest	Farthest
Richton	-46	+40	-44	+52
Deaf Smith	-30	+23	-38	+44
Davis Canyon	-29	+22	-34	+40
Yucca Mountain	-29	+21	-27	+30
Hanford	-25	+19	-33	+37

Table A-45. Criteria for applying the transportation guideline

FAVORABLE CONDITIONS

- (1) Availability of access routes from local existing highways and railroads to the site which have any of the following characteristics:
 - (i) Such routes are relatively short and economical to construct as compared to access routes for other comparable siting options.
 - (ii) Federal condemnation is not required to acquire rights-of-way for the access routes.
 - (iii) Cuts, fills, tunnels, or bridges are not required.
 - (iv) Such routes are free of sharp curves or steep grades and are not likely to be affected by landslides or rock slides.
 - (v) Such routes bypass local cities and towns.

Criterion

All parts of this favorable condition pertain to the access route to the repository. The access route is the road or railspur that must be constructed to connect existing roads or track with the site. Only one part need be present.

- (i) The favorable condition is present if the access route is less than 10 miles long and costs less than \$10 million. These criteria are applied to truck and rail routes separately.
- (ii) If any part of the access route must be constructed over private land, it is assumed that Federal condemnation will be required, and the favorable condition is not present
- (iii) All road or track construction requires cuts and fills. Cuts and fills for generally flat terrain are considered acceptable. The favorable condition is not present if bridges or tunnels are required.
- (iv) The favorable condition is present if the access road is constructed over generally flat terrain.
- (v) The favorable condition is not present if the access route passes through a highly populated area, as defined in 10 CFR Part 960, Subpart A, or 960.5-2-1(c)(2) (Federal Register, Vol. 49, pp. 47754 and 47763, respectively).

Table A-45. Criteria for applying the transportation guideline
(Continued)

-
- (2) Proximity to local highways and railroads that provide access to regional highways and railroads and are adequate to serve the repository without significant upgrading or reconstruction.

Criterion

This favorable condition pertains to that segment of existing track between the outer end of the access route and the nearest State, Federal, or interstate highway and the nearest mainline railroad that does not require upgrading or repair. This segment of road or track should be no longer than 10 miles and cost no more than \$10 million.

- (3) Proximity to regional highways, mainline railroads, or inland waterways that provide access to the national transportation system.

Criterion

This distance refers to the length of the road or track between the outer end of the access route and the nearest State, Federal, or interstate highway or the nearest mainline railroad. This distance should be no more than 30 miles. Distance to a waterway is not considered because a barge shipment would have to offload onto a railroad.

- (4) Availability of a regional railroad system with a minimum number of interchange points at which train crew and equipment changes would be required.

Criterion

All sites have at least one railroad interchange point at the point where the site spur joins the mainline. All other interchanges within 125 miles of the site will be counted. The site with the fewest interchanges will be considered to have the favorable condition present.

- (5) Total projected life-cycle cost and risk for transportation of all wastes designated for the repository site which are significantly lower than those for comparable siting options, considering locations of present and potential sources of waste, interim storage facilities, and other repositories.

Criterion

All sites will be compared; only one site will have the favorable condition present.

Table A-45. Criteria for applying the transportation guideline
(Continued)

- (6) Availability of regional and local carriers--truck, rail, and water--which have the capability and are willing to handle waste shipments to the repository.

Criterion

This favorable condition is present if any carrier--truck, rail, or water--is available within the minimum transportation study area.

- (7) Absence of legal impediment with regard to compliance with Federal regulations for the transportation of waste in or through the affected State and adjoining States.

Criterion

This favorable condition will be addressed as explained in Appendix C.

- (8) Plans, procedures, and capabilities for response to radioactive waste transportation accidents in the affected State that are completed or being developed.

Criterion

Any evidence that emergency-response plans, procedures, and capabilities exist will be favorable. Evidence for all of these is required for a finding that the favorable condition is present.

- (9) A regional meteorological history indicating that significant transportation disruptions would not be routine seasonal occurrences.

Criterion

The repository activity is significantly disrupted if it is not able to meet its annual acceptance rate.

Table A-45. Criteria for applying the transportation guideline
(Continued)

POTENTIALLY ADVERSE CONDITIONS

- (1) Access routes to existing local highways and railroads that are expensive to construct relative to comparable siting options.

Criterion

An expensive access route is considered to be one that costs more than \$10 million.

- (2) Terrain between the site and existing local highways and railroads such that steep grades, sharp switchbacks, rivers, lakes, landslides, rock slides, or potential sources of hazard to incoming waste shipments will be encountered along access routes to the site.

Criterion

This potentially adverse condition is present if the terrain over which the access route must pass is not generally flat and if the access route must cross a river or lake.

- (3) Existing local highways and railroads that could require significant reconstruction or upgrading to provide adequate routes to the regional and national transportation system.

Criterion

This potentially adverse condition is present if a significant reconstruction or upgrading of a truck or rail route costs more than \$10 million. This criterion is applied separately to truck and rail routes.

- (4) Any local condition that could cause the transportation-related costs, environmental impacts, or risk to public health and safety from waste transportation operations to be significantly greater than those projected for other comparable siting options.

Criterion

Examples of local conditions that are potentially adverse are proximity to a bombing range, extreme costs, and despoiling of the environmental and aesthetic qualities of pristine land.

criteria were applied during the ranking process documented in Chapter 7 of the draft EAs.

The process by which the criteria were developed relied heavily on the collective transportation expertise of the ad hoc group. Rules-of-thumb were often used to make estimates in the context of indefinite terms. For example, the cost of a mile of new highway or railroad track is often assumed to be \$1 million when the route traverses flat terrain. Such an estimate might be used when much additional information is not available. The application of such rules, experience, and informed judgment allowed more-definitive criteria to be developed while considering the requirement to judge transportation conditions in the context of "comparable siting options." In other words, the criteria values were developed by fully considering the range and distribution of values for all of the five sites nominated as suitable for characterization.

The comments on the draft EAs noted other inconsistencies in the findings reported for the transportation guideline, particularly for the conditions that contain the term "regional". The DOE then decided to develop criteria for all of the conditions in the transportation guideline. Through repeated discussions with the ad hoc committee members, the final criteria presented in Table A-45 were promulgated in August 1985. Again, the process of criteria development relied on the judgment of the transportation ad hoc group.

A.13 COMMON QUESTIONS REGARDING TRANSPORTATION

A.13.1 PRENOTIFICATION

Many States wish to be notified in advance of certain radioactive-waste shipments.

Whether prenotification results in an increase in safety is the subject of considerable discussion among Federal regulatory agencies and State and local governments. Currently, the NRC, under Congressional mandate, requires NRC licensees to notify States in advance of spent-fuel and certain radioactive-waste shipments (10 CFR 71.97 and 73.37(f)). The DOT requires postnotification of shipments (49 CFR 173.22(d)). In an effort to understand the issue and to gauge the efficacy of the NRC regulation, the DOE sponsored a study (Pellettieri and Welles, 1985). Currently, the DOE and the DOT have completed a joint study that surveyed the State, local, and facility notification requirements for hazardous materials (Dively et al., 1985).

The DOE currently provides State officials with generic notification of its shipments of radioactive material. This notification reviews the type and quantity of shipments but does not designate the time and the date of shipment. For current shipments in support of the OCRWM research and development program, the DOE is supplementing this generic notification with courtesy communications to an appropriate officer of each State through which the shipment will pass. In light of the number of spent-fuel shipments to repositories, the DOE will evaluate its current procedures for tracking radioactive-waste shipments and consider a number of additional options. For

example, an effective real-time shipment-tracking system may be a preferable alternative to prenotification. Decisions will be based on the best technology available and applicable laws and regulations in use at the time of shipment to a waste-management facility.

A.13.2 EMERGENCY RESPONSE

Emergency response to a transportation accident involving radioactive material is another concern of State and local officials.

State and local jurisdictions have the primary responsibility for emergency response to incidents occurring in connection with all hazardous materials, including spent-fuel shipments. Federal assistance can be provided in many ways, however. For example, the DOE will make available from its resources such radiological advice and assistance as is requested and appropriate to protect public health and safety and to cope with radiological hazards. DOE personnel will respond to requests from NRC licensees; Federal, State, and local authorities; and private persons or companies, including carriers. Assistance can be obtained from any one of eight DOE regional centers, which are capable of responding to radiological incidents on a 24-hour basis. Requests for aid are handled directly through the DOE regional centers or through an emergency clearing house called CHEMTREC (Chemical Transportation Emergency Center) that is sponsored and funded by the chemical industry. The DOE offices, when requested, will provide radiation assistance teams.

For States hosting facilities developed under the Act, the DOE will seek to negotiate written agreements that can address assistance and funding for emergency-response preparations. In other States, funding or assistance in lieu of funding (e.g., training courses, equipment, etc.) will continue to be available through the Federal Emergency Management Agency (FEMA) or other Federal agencies. Examples of the type of assistance already provided by the Federal Government are the emergency-response workshops for first responders sponsored by the DOE at various locations in the country each year as part of its compliance training program.

The FEMA has coordinated the development of the interim Federal Radiological Emergency Response Plan (Federal Register, Vol. 49, p. 35896). The interim plan outlines procedures to be taken in the event of nuclear accidents, including those involving the transportation of radioactive waste, and is designed to provide coordinated Federal response in support of State and local governments. Under the plan, State and local governments have the primary responsibility for responding to emergencies; Federal technical assistance is provided on request. In addition, the FEMA has published interim Guidance for Developing State and Local Radiological Emergency Response Plans and Preparedness for Transportation Accidents (FEMA, 1983). This guidance, which is currently being revised, provides a basis for State and local governments to develop emergency plans and improve emergency preparedness for transportation accidents involving radioactive materials.

A.13.3 HIGHWAY ROUTING

A.13.3.1 Highway routing regulations

The routing of radioactive-waste shipments is a primary concern of State, local, and tribal officials. On January 19, 1981, the DOT by its authority under the Hazardous Materials Transportation Act, published a final rule governing the highway routing of radioactive materials. Designated HM-164, this rule has been codified as 49 CFR Parts 171, 172, 173, and 177. The DOE will, of course, comply with all DOT regulations.

According to HM-164, highway carriers of "highway route controlled quantity radioactive materials" (e.g., spent nuclear fuel) are required to use "preferred routes." A preferred route consists of an interstate highway, including the use of interstate beltways or bypasses when available to avoid city centers, or alternative routes that are designated by a State routing agency (which includes the appropriate authorities of Indian Tribes). State-designated alternative routes must be selected in accordance with DOT guidelines for selecting preferred highway routes (DOT, 1984) or an equivalent routing analysis that adequately considers the overall risk to the public.

The DOT stated that it followed three basic concepts in devising a highway-routing framework for radioactive materials:

1. Route selection should be based on some valid measure of reduced risk to the public.
2. Uniform and consistent rules for route selection are needed from both a practical and a safety standpoint.
3. Local views should be carefully considered in routing decisions because routing is a site-specific activity unlike other transportation controls, such as marking and packing (Federal Register, Vol. 46, p. 5299).

The DOT's approach to routing acknowledges that public policy for the routing of radioactive materials should be based on a consideration of the overall risk involved in transporting such materials. The risk depends on such factors as accident rates, total travel time, traffic patterns, population density, road conditions, time of travel, and driver training. Further, the DOT recognized the need to balance local and national interests in routing decisions while providing for uniformity and consistency of transportation regulations. With regard to the acknowledged need to provide for local input in routing decisions, the DOT provided for the designation of alternative routes to interstate highways by State routing agencies in consultation with affected localities, neighboring States, and Indian Tribes and in accordance with DOT guidelines, to ensure the consideration of all impacts and continuity of designated routes.

Carriers of spent fuel may deviate from a preferred route under the following three circumstances:

1. Emergency conditions that would make continued use of the preferred route unsafe.

2. To make necessary rest, fuel, and vehicle-repair stops.
3. To the extent necessary to pick up, deliver, or transfer a large-quantity package of radioactive materials (49 CFR 177.825(b)(2)).

HM-164 has numerous other provisions designed to ensure the safe highway shipment of radioactive materials. These include the requirement for the provision of written route plans to the shipper and specific driver-training requirements, which include knowledge of procedures to be followed in an accident or other emergency.

There are several methods by which the DOE can support the highway-routing efforts of the States and the DOT. On request, the DOE will assist the States as practicable in the evaluation and determination of State-designated alternative routes. The DOE, as the shipper of record, will continue to notify its carriers of the State-designated alternative routes and will instruct that these routes be used during all shipments. Moreover, the carrier will be instructed that all safety and routing requirements must be met and that lack of compliance will result in appropriate sanctions, including the potential suspension of carriers (41 CFR 109-40.103-1). Federal and State reports of carrier performance, postnotification of routes, and DOE tracking of actual shipments will provide mechanisms by which operations can be monitored. In addition to diligent and consistent observance of these currently available procedures, the DOE will continue to coordinate with the States concerning the routing of any highway route controlled quantities (49 CFR 173.403) of radioactive materials shipped by the DOE.

A.13.3.2 State and local ordinances

As discussed in the preceding section, the DOT derives its authority to regulate hazardous-materials transportation principally from the Hazardous Materials Transportation Act (HMTA). The HMTA (Section 112(a)) preempts "...any requirement of a state or political subdivision thereof, which is inconsistent with any requirement set forth in [the HMTA] or regulations issued under [the HMTA]." Thus, State or local actions are not necessarily precluded; only those that are "inconsistent" are preempted. The DOT can, however, grant an exemption from this blanket preemption provision to allow an inconsistent State or local requirement to remain in effect. Such an exemption can be granted if, mainly because of local considerations, the requirement (1) affords an equal or greater level of protection to the public than is afforded by the requirements of the HMTA or of regulations issued under the HMTA and (2) does not unreasonably burden commerce.

In its general discussion of the highway-routing rule, the DOT notes its conclusion that "the public risks in transporting [radioactive] materials by highway are too low to justify the unilateral imposition by local governments of bans and other severe restrictions on the highway mode of transportation" (Federal Register, Vol. 46, p. 5299).

Appendix A to 49 CFR Part 177 delineates DOT policy regarding the consistency of State and local rules with DOT highway-routing requirements for the purpose of advising State or local governments how they can exercise their responsibilities with respect to the regulation of motor carriers. The DOT generally regards State and local requirements to be inconsistent if they--

- Prohibit the transportation of large-quantity radioactive materials by highway between any two points without providing an alternative route for the duration of the prohibition.
- Conflict with NRC or DOT physical-security requirements.
- Require additional or special personnel, equipment, or escort.
- Require additional or different shipping paper entries, placards, or other hazard-warning devices.
- Require filing route plans or other documents containing information that is specific to individual shipments.
- Require prenotification.
- Require accident or incident reporting other than as immediately necessary for emergency assistance.
- Unnecessarily delay transportation.

A.13.4 RAILROADS

A.13.4.1 Railroad routing

There are no regulatory requirements for the routing of rail shipments. Rail-shipment routes depend largely on the railroad to which the shipment is originally consigned and how that (and each successive) railroad handles interconnections with other railroads.

A.13.4.2 Rail regulations

Several government agencies perform inspection-and-enforcement activities to promote the safe transportation of radioactive materials on the nation's railroads. Since rail is a predominantly interstate mode of transportation, the Federal Government has long been considered the entity best equipped to develop, promulgate, and enforce a uniform set of safety regulations for the transportation of hazardous materials by rail.

The safety and safeguards regulations for shipments of radioactive material by rail, in many cases, are the same as those for highway shipments. The NRC has issued general routing guidelines for rail shipments of spent

fuel, which are included in its physical-protection requirements that were promulgated to guard against acts of sabotage for both rail and truck spent-fuel shipments. The DOT has issued specific rules limiting both the number and the duration of rail stops and designating the placement of cars carrying spent fuel in the makeup of the train. In addition, there are standards for track quality and other operating features of importance to safety of rail transport.

Shippers who prepare material for rail transportation are required to comply with DOT regulations found in 49 CFR Part 173 before offering any hazardous material shipment to a carrier. The responsibilities of rail carriers of radioactive waste are outlined in DOT regulations 49 CFR Part 174. In accepting a shipment, the carrier inspects it visually to ascertain that the hazardous material is not leaking, that specific rail equipment (air and handbrakes, journal boxes, and trucks) is working properly, and that appropriate placards are provided. The carrier cannot accept packages that are leaking or damaged. In addition to the DOT requirements, rail companies inspect railcars periodically to ensure that they are mechanically safe for operation. In particular, certain equipment is routinely inspected at interchange points by the carrier.

Carrier operations are also subject to DOT regulations covering safety enforcement procedures, track safety standards, and accident-reporting procedures. Under the conditions of 49 CFR 171.15 and 171.16, the carrier must notify the DOT immediately of any unintentional release of a hazardous material during the course of transportation and must submit a written hazardous materials incident report to DOT within 15 days of such an event.

Although jurisdiction over the transport of radioactive waste by rail is vested primarily in the Federal Government, States and local governments that wish to assume specific responsibilities in this area also have a role. The Federal Rail Safety Act (45 U.S.C. 434) directs that a State may enforce its own railroad safety regulation provided that the State regulation is (1) consistent with Federal regulations, (2) necessary to eliminate or reduce an essentially local safety hazard, and (3) not a burden on the free flow of interstate commerce.

The DOE's Office of Civilian Radioactive Waste Management (OCRWM) is investigating means for facilitating a cooperative effort among affected Federal and State agencies and the railroad industry in forging shipping arrangements that are safe, efficient, and equitable. There appears to be a strong willingness by all affected parties to work toward this goal.

The DOE will reinforce the DOT's and the NRC's inspection-and-enforcement activities through the establishment of a comprehensive quality-assurance and quality-control program to address each aspect of the transportation process, including the integrity of the shipping casks and the procedures for handling the casks. The quality-assurance program will implement systematic procedures designed to ensure and provide demonstrable evidence that program goals, such as safety, reliability, and maintainability, are achieved in a cost-effective manner.

A.13.4.3 Dedicated trains

The use of "dedicated trains" involves the designation of specific equipment (locomotives, cask cars, buffer cars, and cabooses) for the use of a particular commodity between fixed origin and destination points. In many respects, it is similar to the "sole-use" vehicle that is commonly employed by motor carriers for specific commodities (one example is the transportation of bulk, low-specific-activity radioactive material).

Special arrangements to expedite the movement of dedicated trains can be made among railroads. For example, the equipment "dedicated" for sole use may be owned by the originating carrier. This equipment could be used for the full length of the move. There may be no switching or interchange with other carriers at terminals along the route. After delivery, the empty cars are returned to the origin for the next movement, possibly under the same expedited process as the loaded train. The originating carrier and the carriers that own and operate the rail lines to be used by the dedicated train would agree on the apportionment of revenues among themselves for the entire move.

A.13.5 INSURANCE COVERAGE FOR TRANSPORTATION ACCIDENTS

The Price-Anderson Act of 1957 (42 U.S.C. Sections 2014 and 2210, as amended) provides extensive liability coverage for damages suffered by the public in the event of nuclear accidents at certain facilities (which include commercial nuclear power reactors and DOE contractor-operated facilities) or accidents that occur in the course of transportation to or from such facilities. Liability coverage extends to all potentially responsible parties (except, in some instances, the Federal Government, whose liability would be covered under the Federal Tort Claims Act) and is not limited to parties who actually purchase insurance or enter into indemnity agreements with the Federal Government.

State law is generally used to determine liability and the extent of damages in the event of a nuclear incident; the Price-Anderson Act in turn establishes a system for paying for those damages. The Act places restrictions on the use of State law in the event of an "extraordinary nuclear occurrence" (ENO) at certain facilities--an occurrence that involves substantial offsite releases of radiation and is likely to result in substantial offsite damages to persons or property. When the Federal Government determines that an extraordinary nuclear occurrence has occurred, certain defenses available under State law must be waived. One waiver requires the imposition of strict liability, without proof of negligence on the part of any responsible party. Defenses related to governmental immunity are also waived. The Price-Anderson Act further declares that in the event of an extraordinary nuclear occurrence, defenses based on statutes of limitations will be waived if a suit is brought within "three years from the date that the claimant first knew, or reasonably could have known, of his injury or damage and the cause thereof, but in no event more than twenty years after the date of a nuclear incident." A State statute of limitations that allows a greater period of time for filing suit would remain in effect.

Another important feature of the Price-Anderson Act is the monetary limitation on liability. To the extent that damages exceed the amount of coverage required by the Act, all responsible parties are relieved of further liability; Congress is then required to investigate the incident and take appropriate action.

The Price-Anderson Act provides for liability coverage through a system of private insurance and government indemnity. Under the Act's private insurance system, utility owners of large NRC-licensed commercial nuclear power reactors are required to maintain the maximum amount of insurance available from private sources (currently, \$160 million). Should claims arising from a nuclear incident (related to the activities of such NRC licensees) exceed the amount of primary insurance, all licensees of large nuclear power reactors would be assessed up to \$5 million per reactor. With 98 large reactors now licensed to operate (as of January 1986), a second layer of coverage is provided in the amount of \$490 million. Both forms of coverage provide a total of \$640 million in the event of a serious nuclear incident at a nuclear power plant or an incident occurring in the course of transportation to or from such a facility.

The Price-Anderson Act also authorizes the DOE to enter into indemnity agreements with its contractors for activities, under contract and conducted for the benefit of the United States, that involve "the risk of public liability for a substantial nuclear incident." The indemnity coverage under such contracts provides that, in the event of a nuclear incident arising out of, or in connection with, a contractual activity, the contractor and any other person who may be liable would be indemnified by the DOE, up to the statutory limit of \$500 million. Indemnity coverage under DOE agreements further extends to nuclear incidents arising in the course of transportation to or from contractor locations. The DOE does not require contractors to carry additional liability insurance because the cost of any such insurance would be passed on to the DOE. Since the enactment of the Nuclear Waste Policy Act, the DOE has indicated that indemnity agreements based on the Price-Anderson Act will be included in its contracts for the operation of any DOE facility associated with the waste-management program (e.g., a geologic repository and MRS facility, if approved by Congress). Under the indemnity agreement, the DOE is to indemnify the facilities' operating contractor and any other person who may be liable for a nuclear incident arising out of, or in connection with, radioactive waste management. Coverage for waste-management activities would extend to transportation to or from a waste-management facility.

Congressional review of the Price-Anderson Act is now under way and is expected to be completed by 1987, when the Act will expire unless reauthorized. The DOE has offered recommendations to Congress pertaining to the Act's contractor indemnity system and the application of that system to activities conducted under the Nuclear Waste Policy Act. Such recommendations include the following:

- Extended liability coverage. While a limitation on liability is supported, the DOE has recommended that the extent of coverage under DOE indemnity agreements be comparable to that afforded by large commercial utilities.

- Explicit coverage of activities conducted under the Nuclear Waste Policy Act. While the DOE believes that the present language of the Price-Anderson Act is sufficient to permit indemnification coverage for nuclear waste operations, explicit coverage under the Act is supported.
- Application of ENO provisions to waste-management activities. The DOE supports the extension of the Act's ENO provisions, with the related waiver of defenses, to incidents connected with the transportation, storage, and disposal of civilian and defense high-level waste.
- Source of funding. The DOE supports the provision of liability coverage for waste-management activities conducted under the Nuclear Waste Policy Act through expenditures of the Nuclear Waste Fund (which in turn is financed through fees paid by the generators and owners of radioactive waste).

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Appendix B

AVAILABILITY OF REFERENCES

Appendix B

AVAILABILITY OF REFERENCES

B.1 REFERENCES CITED IN ALL EAs

The references cited in all of the draft and the final environmental assessments (EAs) are available for public review in DOE reading rooms at the following locations.

U.S. Department of Energy
Public Reading Room
FOI, Room 1E-190
1000 Independence Avenue, S.W.
Washington, DC 20585

Albuquerque Operations Office
National Atomic Museum
Kirkland Air Force Base East
Albuquerque, NM 87116

Chicago Operations Office
9800 South Cass Avenue
Argonne, IL 60439

Idaho Operations Office
550 Second Street
Idaho Falls, ID 83401

Nevada Operations Office
2753 South Highland Drive
Las Vegas, NV 89109

Oak Ridge Operations Office
Federal Building
Oak Ridge, TN 37830

Richland Operations Office
Federal Building
Richland, WA 99352

San Francisco Operations Office
Wells Fargo Building
1333 Broadway
Oakland, CA 95612

Savannah River Operations Office
Savannah River Plant
Aiken, SC 29801

B.2 REFERENCES CITED IN THE EA FOR THE BASALT (HANFORD) SITE

The references cited in the EA for the Hanford site are available for public review at the following locations:

Idaho

Boise Public Library and
Information Center
715 Capitol Boulevard
Boise, ID 83702

Lewiston City Library
428 Thain Road
Lewiston, ID 83501

Coeur D'Alene Public Library
703 Lakeside Avenue
Coeur D'Alene, ID 83814

University of Idaho Library
(Federal Depository)
Moscow, ID 83843

Oregon

Portland State University
(Federal Depository)
Bradford Price Millar Library
934 Southwest Harrison
Portland, OR 97207

Umatilla County Library
214 North Main Street
Pendleton, OR 97801

Washington

University of Washington Libraries
M-171 Library, FM-25
Seattle, WA 98195

Eastern Washington University
John F. Kennedy Memorial
Cheney, WA 99004

Central Washington University
D and 11 Street
Ellensburg, WA 98926

Washington State University Library
Holland Library, Room 221
Library Road
Pullman, WA 99164-5610

Washington State Library
(Federal Depository)
Temple of Justice
Olympia, WA 98504

Mid-Columbia Library
405 South Dayton
Kennewick, WA 99336

Pasco Public Library
1320 West Hopkins
Pasco, WA 99301

Richland Public Library
Swift and Northgate
Richland, WA 99352

Seattle Public Library
1000 Fourth Avenue
Seattle, WA 98104

Spokane Public Library
Comstock Building Library
West 906 Main Avenue
Spokane, WA 99201

Fort Vancouver Regional Library
1007 East Mill Plain Boulevard
Vancouver, WA 90663

Walla Walla Public Library
238 East Adler
Walla Walla, WA 99362

Prosser Public Library
902 Seventh Street
Prosser, WA 99350

U.S. Department of Energy
Reading Room, Hanford Science
Center
825 Jadwin Avenue
Richland, WA 99352

State of Washington Dept. of Ecology
Office of High-Level Nuclear Waste
Management
Reference Center
5826 Pacific Avenue
Lacey, WA 98504

Yakima Valley Regional Library
102 North Third Street
Yakima, WA 98901

B.3 REFERENCES CITED IN THE EA FOR THE SALT SITES

The references cited in the EAs for the Davis Canyon, Utah, Deaf Smith, Texas, and Richton, Mississippi, are available for public review at the following locations:

Louisiana

Minden Nuclear Waste Information Office
221 Main Street
Minden, LA 71005

Bienville Parish Library
604 South Maple
Arcadia, LA 71001

Webster Parish Library
521 East and West Streets
Minden, LA 71005

Mississippi

Richton Nuclear Waste Information Office
103 Dogwood
Richton, MS 39476

Harrison County Library
14th Street and 21st Avenue
Gulfport, MS 39510

Pine Forest Regional Library
Main Street
Richton, MS 39476

Jackson-George Regional Library
3214 Pascagoula Street
Pascagoula, MS 39567

Jackson Metropolitan Library
301 North State Street
Jackson, MS 39201

Harriette Person Memorial Library
College Street
Port Gibson, MS 39150

Hattiesburg Public Library
723 Main Street
Hattiesburg, MS 39401

Laurel-Jones County Public Library
530 Commerce Street
Laurel, MS 39440

Jones County Junior College Library
Front Street
Ellisville, MS 39437

Texas

Deaf Smith County Library
211 East Fourth Street
Hereford, TX 79045

Rhoads Memorial Library
103 Southwest Second Street
Dimmitt, TX 79027

Swisher County Library
127 Southwest Second Street
Swisher County Memorial Building
Tulia, TX 79088

Gabie Betts Burton Memorial Library
217 S. Karney St.
Clarendon, TX 79226

Canyon Public Library
301 16th Street
Canyon, TX 79015

Austin Public Library
800 Guadalupe Street
Austin, TX 78768

Texas (continued)

Amarillo Public Library
413 East Fourth Street
Post Office Box 2172
Amarillo, TX 79189

University of Texas General Library
Post Office Box P
Austin, TX 78712

Texas Nuclear Waste Programs Office
Sam Houston Office Building, Room 204
200 East 14th Street
Austin, TX 78711

Hereford Nuclear Waste Information
Office
115 East First Street
Hereford, TX 79045

Tulia Nuclear Waste Information Office
Griffith Estate Building
100 S.E. Second
Tulia, TX 79088

Utah

Moab Nuclear Waste Information Office
471 South Main Street No. 3
Moab, UT 84532

Monticello High School Library
Media Center
55 North Second Street West
Monticello, UT 84535

Monticello Nuclear Waste Information
Office
San Juan County Courthouse
117 South Main Street, Room 12
Monticello, UT 84535

San Juan County Library
50 West First Street South
Blanding, UT 84535

Grand County Public Library
25 South First Street East
Moab, UT 84532

Mesa County Public Library
530 Grand Avenue
Grand Junction, CO 81501

Grand County High School Library
300 South 100 East
Moab, UT 84532

Salt Lake City Public Library
2197 East 7000 South
Salt Lake City, UT 84121

San Juan County Library
266 North Main Street
Monticello, UT 84535

University of Utah
Marriott Library
Salt Lake City, UT 84112

B.4 REFERENCES CITED IN THE EA FOR THE TUFF SITE

The references cited in the EA for the Yucca Mountain site are available for public review at the following locations:

Amargosa Valley Community Library
Star Route 15
Box 40-T
Amargosa Valley, NV 89020

Beatty Community Library
4th and Ward
P.O. Box 128
Beatty, NV 89003

Clark County Library
1401 E. Flamingo
Las Vegas, NV 89109

Lincoln County Library
P.O. Box 330
Pioche, NV 89043

Nevada State Library
401 N. Carson
Capitol Complex
Carson City, NV 89710

University of Nevada at Las Vegas
James R. Dickinson Library
4505 Maryland Parkway
Las Vegas, NV 89154

United States Department of Energy
Nevada Operations Office
Public Reading Room
2753 South Highland
Las Vegas, NV 89109

Law Library
Nye County Courthouse
P.O. Box 393
Tonopah, NV 89049

Nevada Legislative Council Bureau
Research Library
Legislative Building
Capitol Complex
Carson City, NV 89710

Northern Nevada Community College
Learning Resource Center
901 Elm Street
Elko, NV 89801

University of Nevada at Reno
Getchell Library
Reno, NV 89557

Washoe County Library
301 Center Street
Reno, NV 89502