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REGULATABLE ELEMENTS IN THE HIGH-LEVEL
WASTE MANAGEMENT PROGRAM

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December 1979

Lawrence
Livermore
Laboratory

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This work was supported by the United States Nuclear Regulatory Commission under a Memorandum of Understanding with the United States Department of Energy.

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December 26, 1979
WAI 79-445-G

FOREWORD

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December 26, 1979
WM 79-445-D

ABSTRACT

Regulatable elements of a deep geological nuclear waste isolation system are those characteristics of a candidate system which need to be specified to achieve control of its performance. This report identifies the regulatable elements with respect to waste form, repository design, site suitability, and the modeling and decision analysis processes. Regulatable elements in each section are listed and described briefly as they affect the short-term and long-term performance of a deep geological repository.

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INTRODUCTION

The Nuclear Regulatory Commission (NRC) is responsible for regulating the management and disposal of nuclear wastes from licensed facilities.

The Lawrence Livermore Laboratory (LLL) is providing technical assistance to help the NRC develop standards for the management and disposal of high-level and transuranic wastes in deep geological repositories. The objectives of the LLL program are to provide an information base and a methodology for developing standards for (1) waste form performance, (2) repository site suitability, and (3) repository design performance.

Regulations governing the handling and disposal of high-level nuclear wastes are drafted with the general purpose of preventing hazards to the health and safety of the human population. This basic theme is enunciated in the statutes which authorize the NRC to promulgate these regulations. Hazards are considered without specific limitations, and therefore, it is the task of the drafters of regulations to delineate the extent of the regulatory protection. The basic policy for protection of the public health and safety must be seen in the perspective of the economic, time, and resource limitations of society. In the case of the nuclear reactor regulations (10CFR50), a balance has been achieved in the ALARA* concept.

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*ALARA is defined as: "as low as reasonably achievable taking into account the state of technology, and the economics of improvement in relation to benefits to the public health and safety, and other societal socioeconomic consideration:" (10 CFR Section 50.34a).

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This report provides a basis for specifying those factors of a deep geological nuclear waste isolation system which should be regulated in any rational scheme for protection.

The report is organized into five sections. The first section identifies the scope and extent of the required regulations. In Sections 2 and 3, regulatable elements are listed and described, for short-term and long-term performances of the waste form and repository design parts of the waste isolation system. Section 4 deals with geologic and hydrologic elements. Regulatable elements of measurement techniques are described, and considerations that must be included in the site selection process are identified. Section 5 is a discussion of the regulatable elements of the modeling and decision analysis process.

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1.0 Goals

The regulations for the nuclear waste isolation system must be consistent with two distinct goals:

1. The health and safety of workers and of the general public must be protected during all phases of storage and operation of the disposal facility. The period for this short term is defined as the time up to the decommissioning of the repository.
2. The health and safety of the population must be protected following decommissioning (long-term) of the disposal facility. Post-sealing monitoring is desired for as long as administrative control over the repository can be maintained. Decommissioning of a waste disposal facility means losing active control of the waste storage process. Protection of public health and safety under these conditions requires (i) measurement and analysis of the performance of the repository, (ii) assurance of thoroughness and accuracy of the measurements and analysis, and (iii) determination of the standards required for such performance.

The goals are to be achieved by enforcement of regulations. The regulations must be based on regulatable elements of a deep geological nuclear waste isolation system. Regulatable elements are those characteristics of a candidate nuclear waste isolation system which need to be specified to achieve control of the ultimate performance of the system. These characteristics must be observable, quantifiable and controllable. Most geological and hydrological elements, while uncontrollable themselves, must be considerations in the regulatable site selection process.

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2.0 Regulatable Elements of Waste Form Performance

2.1 Waste Form

Nuclear wastes which require deep geologic isolation can be in different forms. High level reprocessed waste may exist, for example, as finely divided oxides, as glass monolith, pellets, or as synroc. Unreprocessed spent fuel may be placed in the canister in its original assembly, disassembled, or chopped into small pieces.

Nuclear waste should be in a non-dispersible form selected for chemical and thermal stability and low water solubility. Regulatable characteristics of waste form are described below.

2.1.1 Short-term Performance

1. Dispersibility. If the nuclear waste form is generated as finely divided particulate material, it should be further processed into non-dispersible form, i.e., pellets. Particle sizes smaller than 10 microns present a serious health hazard since they can become airborne and enter lungs through inhalation.
2. Chemical stability. The waste form should not decompose spontaneously or under the influence of radiation (radiolysis). It should not readily react with water, air, rock, or engineering materials. Chemical stability of the waste form can be evaluated from thermodynamic considerations.
3. Thermal stability. Waste form should be a solid under the temperature conditions anticipated in the emplacement environment. It should not interact corrosively with the canister material and should have a low vapor pressure at expected temperatures, to preclude pressure build-up in the canister.

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4. Solubility. Waste form should have low solubility in water to minimize potential spread of contamination in the event of an accident where water is involved. Accident situations where direct water contact is possible include cases of canister rupture followed by fire (which would be fought with water), or a ruptured canister falling into a body of surface water.

2.1.2 Long Term Performance

1. Dispersibility. Nuclear waste as finely divided oxides can be physically transported by groundwater as a suspension. The aggregate surface area of the finely divided particles is large. If a process is surface area dependent, as dissolution or leaching might be, its rate can be accelerated. Waste form should therefore be processed into densely compacted form.
2. Chemical stability. Waste form should not spontaneously decompose and should be stable to ionizing radiation. It should have limited chemical reactivity in its environments.
3. Thermal stability. Waste form should be in the solid state under all predictable temperature conditions after repository decommissioning. It should have low vapor pressure to preclude pressure build-up in the canister in the event of accidental temperature excursions.
4. Solubility. Waste form should exhibit low groundwater solubility which will prolong the dissolution/leaching process and minimize the rate of groundwater transport of the radionuclides to the biosphere.
5. Synergism. A second waste form which will affect the solubility of the first waste form in a synergistic manner should not be placed in the same repository. Combinations of chemicals which will adversely

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affect the geochemical retardation of radionuclide transport in the medium should be avoided.

2.2 Canister

The canister is the primary barrier against the release of radionuclides to the environment during the pre-emplacement period. In the post-emplacement period, it is the second barrier against groundwater attack. The regulatable characteristics of the canister are described below.

2.2.1 Short-term Performance

1. Material of construction. The primary failure mode of the emplaced canister is corrosion. The canister material should be selected to perform in the emplacement environment and to remain intact and retrievable for the time that retrievability must be maintained.
2. Mechanical integrity. Since the canister is the primary barrier against radionuclide release during pre-emplacement, it should be designed to survive accidental drops during routine emplacement operations and the stresses of retrieval operations.
3. Design considerations. Since the corrosion processes are strongly temperature dependent, the temperature at the canister surface should be controlled when in the emplacement medium. Temperature and thermal flux can be controlled by limiting the amount of nuclear waste through canister design and by specifying the age of the waste. Criticality accidents can also be precluded through canister design.

2.2.2 Long-term Performance

1. Material of construction. The canister is the second in the series of engineered barriers against groundwater contact with nuclear

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waste. The material should resist corrosion to provide protection against ground water intrusion.

2. Synergism. The synergistic effect of the corrosion products of the canister material on the dissolution of the nuclear waste form should be considered. The corrosion products should not adversely affect the geochemical retardation of radionuclide transport in the medium.
3. Design considerations. Canister design should limit the nuclear waste content to control the surface temperature of the canister when placed in the emplacement environment.

2.3 Packaging

Packaging refers to the assemblage of engineered barriers placed in the repository medium for the isolation of nuclear waste from the biosphere. Packaging is the most important engineered barrier against ground water intrusion. It should be designed to provide protection against the emplacement environment. Besides resisting the corrosive attack of the groundwater, the packaging must support the lithostatic overburden and the thermal stresses resulting from the heat generated in the nuclear waste assembly. The regulatable characteristics of packaging are described below.

2.3.1 Short-Term Performance

1. Corrosion. Packaging material should be selected to perform in the emplacement environment over the period of retrievability and to provide a barrier against groundwater intrusion.
2. Mechanical integrity. Mechanical strength of the emplaced package will deteriorate due to corrosion. The waste package should be

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designed to allow successful retrieval of the canister and not collapse around the canister during the period when the retrievability option may be exercised.

3. Design considerations. Package surface temperature must be controlled since corrosion rate is strongly temperature dependent. The temperature and the resultant thermal stress in the medium during normal repository operations must be controlled through the package design.

2.3.2 Long-term Performance

1. Radionuclide transport retardation. The long-term performance is measured by the ability of the emplaced package to retain the radionuclides or to limit the rate of release. Selection of materials such as zeolites for packaging material should be required, to serve this purpose.
2. Corrosion. In the selection of the packaging materials we should exclude material combinations that will enhance the corrosion rate of one or more of the materials through electrolytic action.
3. Synergism. The corrosion products of the packaging material should not adversely affect the geochemical retardation of the radionuclide transport in the medium, nor should they synergistically affect the dissolution of the waste form in the groundwater.

2.4 Monitoring Requirements

Continuous surveillance of waste package and the repository following the emplacement of the nuclear waste in its canister serves several purposes: radioactive safety, retrievability, and validation of package condition

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modeling for both short- and long-term prediction. A measured low radioactivity level in the repository will mean a satisfactory package performance and, more important, a safe occupational environment. Data such as temperature, thermal gradient, electrical conductivity, stress level, and strain rate on both the package and the repository can be analyzed to assess our predictive model of package condition and package/medium interaction for near-term and validate them for use in long-term prediction. Data from monitoring will also verify canister retrievability. The regulatable characteristics of monitoring are described below.

2.4.1 Short-term Performance

1. Radiation level. A continuous radiological monitoring should be performed to assure a safe work environment for the operating personnel and to protect the health and safety of the general public.
2. Temperature/thermal gradient. The surface temperature of the canister/package should be monitored, since corrosion rate is strongly temperature dependent. Information on the thermal gradient is required for the assessment of thermal stress and brine migration problems.
3. Package movement. Successful retrieval of an emplaced package in bedded salt or domed salt requires precise positioning of retrieval machinery with respect to the package. Due to lithostatic stress, the effect of brine migration, or gravity, the package may change its position or orientation with time. The package position and orientation should be monitored periodically to ensure retrievability.
4. Corrosion. The mechanical strength of an emplaced package will deteriorate with time due to corrosion. Corrosion rate is determined

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by the temperature and by the chemical characteristics of the groundwater. The properties of the groundwater that should be measured include hydrogen ion activity (pH), oxidation potential (Eh), and the concentration of the ionic species.

2.4.2 Long-term Performance

1. Dissolution. The release rate of the radionuclides is determined by the temperature and by the chemical characteristics of the groundwater. The groundwater pH, Eh, and composition should be monitored for information about post-closure performance.
2. Synergism. The dissolution (leaching) rate of the waste form may be synergistically affected by the presence of certain ions in the groundwater. Special effort should be made to determine their presence and the concentration level for corrective action prior to repository closure.

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3.0 Regulatable Elements of Repository Design Performance

3.1 Repository Structure and Operation

3.1.1 Short-term Performance

The following regulatable elements are related to the structural performance of the repository during the period before decommissioning and to the short-term performance associated with the operation of the repository. All regulations should comply with OSHA and MSHA standards. Radiation exposure to operating personnel and to public should comply with 10CFR20.

1. Waste Heat Loading. The waste heat loading should be such that the rock thermomechanical behavior does not prevent retrieval or induce large scale failure of mined openings or overlying strata.
2. Ventilation. The ventilation system should be able to perform the necessary air and heat transfer functions as construction proceeds without spreading accidental airborne radioactivity. The ventilation system should have emergency power. It should control the flow of effluents off-site.
3. Repository Layout. Several aspects, such as ventilation, structural integrity, and secure surface facilities, must be satisfied simultaneously. The trade-offs must be recognized and analyzed. The number of shafts, shaft placement, and the number of levels in the repository are included in repository layout. The layout should be adaptable to account for unforeseen variations in site geology discovered in the mining process.
4. Drift Dimensions and Spacings. Conservative practices are required to achieve an adequate safety factor in the stability of the repository.

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5. Contingency Planning for Anomalies. The operator must consider all credible events, form contingency plans, and demonstrate ability to carry out contingency plans. In particular, plans for gas or water intrusion and rock burst must be considered. There must be procedures for cleanup after an accident.
6. Floor Loading. The weight and frequency of traffic can result in damage to floors that could prevent retrieval.
7. Seismic Vibration Response. It is not expected that a seismic event would damage the repository, but the reliability of the communication link with the surface should be regulated, and the effect of seismic motions on shafts and shaft seals considered.
8. Mined Rock Handling. From an environmental standpoint, the storage and disposal of mined rock should be regulated.
9. In-Situ Monitoring. It will be necessary to instrument the repository for monitoring structural stability and response to mining operations. Undesirable trends would necessitate corrective action.
10. Surface Facilities and Operations. The surface facilities and operations should obey all regulations applicable to fuel cycle operations. Certain facilities must have safe-shutdown-earthquake and safe-shutdown-power outage capabilities. Among these facilities are radiation handling facilities, shafts, and filter houses.
11. Radwaste Disposal Systems. The treatment of radioactive waste generated on-site should be handled locally with limited effluent.
12. Waste Types and Mixtures. Different waste forms and types require different equipment and procedures and present different hazards. For example, TRU waste in 55 gallon drums could pose a fire hazard. It is preferable to segregate operations.

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13. Concurrence of Construction and Emplacement. Repository construction and waste emplacement at the same time creates operational problems for the filters and ventilation systems and makes possible the interaction of the risks of both operations. In general, air streams used for the cooling of radioactive waste should not be used for other ventilation needs.
14. Shaft Conveyances. The shaft for high-level waste and for the men and material shaft must be separate, have emergency power, limited drop, no hang-up, and be competent to withstand a design basis seismic event.
15. Waste Handling Equipment and Procedures. These should be designed to limit exposure to personnel. The design, including contingency plans for failures due to equipment or human factors, should be regulated.
16. Traffic Control of Subsurface Vehicles. Extensive movement of men and material will occur in the repository. This is a local transportation problem with the usual risks that must be controlled by the usual regulations. The traffic route for waste must be separate from the traffic route of men and material.
17. Dewatering Requirements. The ability to pump out excess water during the operational phase and any water encountered in the mining process must exist within the repository. Storage of contaminated water must be provided.
18. Criticality Control. The design must prevent criticality accidents under all credible scenarios.
19. Fire Control. The operator should have equipment and trained personnel necessary for fighting fires.

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20. Power Systems. Backup, noninterruptable power systems are needed for systems important for health and safety from the standpoint of waste.
21. Emplacement and Retrieval Mechanisms. These should be designed to be compatible with each other. They should be designed to limit exposure to personnel and should cause no damage to the waste form package.
22. Emplacement Methods and Sequence. Emplacement methods and sequence should isolate emplaced waste from current and future activities.
23. Special Nuclear Material (SNM) Control and Accountability. A material control and accounting system will be required to assure that unauthorized access or removal is prevented.
24. Retrieval Capability. The ability to retrieve all emplaced waste and move it to the surface must be demonstrated. This includes the ability to make accommodations for safe surface storage in a timely manner or to transport the waste away from the site.

3.1.2 Long-term Performance

Some elements of structural performance impact on the long-term performance of the repository.

1. Subsidence. Structural collapse could propagate fractures away from the repository with adverse effects on aquifers and seals. This could also accelerate waste migration. Regulations are required on the mine design to limit this effect.
2. Waste Heat Loading. The thermomechanical response of the medium could produce new hydrological flow paths and enhance existing

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hydrological flow paths. The waste heat loading must be regulated to limit the thermomechanical response.

3.2 Repository Containment

The following regulatable elements control long-term risks related to repository containment performance.

1. Engineering for Decommissioning. The repository and its elements should be designed to allow safe, efficient decommissioning of the repository. The plan should be worked out in detail before construction starts and updated as mining proceeds.
2. Effect of Mining on Hydrological Parameters. Excavation techniques that do not induce fracture flow paths should be used in mining the repository.
3. Engineered Barriers. The repository should include engineered barriers that keep the waste package dry as long as practical and then limit the transport of radionuclides from the repository.
4. Repository Layout. The geometry of the repository should be regulated to preserve a waste-free zone near the shaft.
5. Shaft and Borehole Seals. Seals should be designed using demonstrated, modelable techniques. The techniques may vary with rock type and site geology.
6. Backfill: Materials, Methods and Timing. Backfill affects transport properties, recharge time, thermal conduction, and structural stability. Backfill materials, methods, and timing must be regulated to limit these aspects appropriately.

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7. Validation of Predictions Prior to Decommissioning. Since safe performance of the repository is to be judged on the basis of predictions generated by models, the models should be validated with data obtained during the operational period, wherever possible.

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4.0 Regulatable Elements of Site Suitability

The selection process for identifying a suitable site for a nuclear waste isolation system can be regulated. The measurement techniques can be regulated to provide accurate information for that process. Although the geology and hydrology of the site cannot be controlled, certain geologic and hydrologic features must be considered in the selection process. In Section 4.1, we identify the regulatable elements of the measurement technology. In Sections 4.2 through 4.7, we describe the geologic and hydrologic considerations required for the selection process.

4.1 Measurement Technology

1. Data-type Requirements. The types of information needed for site evaluation during the licensing procedure must be specified.
2. Precision and Accuracy. The degree to which each required datum must be determined should be specified. This specification may be superseded by specifications of measurement technology, procedures, density, and quality control.
3. Instrumentation. It is necessary to specify acceptable instrumentation and techniques to ensure that needed information is collected acceptably.
4. Data Collection Procedures. The quality of some measurements is dependent on the procedure used to perform the measurement. Procedures must be specified in these cases.

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5. Measurement Density. The location and density of tests, especially borings, must be controlled to ensure that while the site is described adequately, site integrity is maintained.
6. Quality Control. Procedures necessary to ensure the quality and reliability of the data must be specified.
7. Data Interpretation Models. The procedures by which data are converted to model parameters should be specified. The interpretation of some information (especially field information) relies on professional judgment and can be evaluated only by peer review.
8. Environmental Monitoring. During operations at a repository site, ongoing measurements must be made to monitor the effect of those operations on the environment. This requires that baseline measurements of environmental parameters be made before the start of operations of any type at the site. Environmental monitoring may include hydrological information from wells in the region of the site, geophysical logs of boreholes in the site area, surface leveling surveys of the site, and surface air, water, and soil composition. Many of these items should be measured periodically during the operation of the repository and some for a period after decommissioning.

4.2 General Geology

1. Depth of Repository Layer. The repository layer should be deep enough to preclude the possibility of breach by surficial erosion or

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other surficial activities. The maximum depth will be limited by rock mechanical constraints.

2. Lateral Extent. The repository layer and surrounding layers should be continuous over sufficient lateral area to ensure that emplaced waste will be sufficiently isolated from surrounding aquifers.
3. Thickness. The repository layer should be thick enough to ensure the integrity of the repository as a barrier to waste migration.
4. Structure. The structure of the site area and region should be sufficiently understood so that performance modeling may be applied. Areas of complex folding and/or faulting must have a positive or minimal negative effect on waste migration.
5. Natural Resource Potential. The site area should not contain constituents which in the foreseeable future may be economically desirable resources. These resources include hydrocarbons, industrial and strategic minerals, groundwater, geothermal resources, and facilities for underground storage. Areas should be avoided where any foreseeable exploration or exploitation activity could compromise the site.
6. Stratigraphic Sequence. Soluble repository layers such as bedded salt should be bounded above and below by aquitards such as tight shales, to minimize communication of the repository layer with surrounding aquifers.
7. Geometry. In massive repository units, such as salt domes or granite bodies, it is important that the surrounding rocks be suitable aquitards or that the massive unit act as a deterrent to groundwater flow.

4.3 Tectonics and Seismology

1. Tectonic Framework. The tectonic framework of a site should be evaluated. It is an indication of the complexity of the site and of the potential for future events that may disrupt the site, such as faulting and volcanic activity. Included in the tectonic framework are tectonic style and the ages of various tectonic events that have affected the region.
2. Fracturing. The joints and fractures in the repository medium and rocks surrounding it may provide a flow path for groundwater and should be considered in site selection.
3. Faulting. Faults may provide interconnections between the repository layer and aquifers and they may interconnect aquifers in a manner that would adversely affect isolation.
4. Earthquake Potential. The potential for active faulting at the site must be evaluated. Actual displacements through the repository or new interconnections between aquifers or between aquifers and the surface would adversely affect isolation.
5. Diapirism. Active diapiric movements in salt could affect isolation of waste. Domes proved to be undergoing movement at present should be excluded. Sites in salt domes should not be where these movements might be induced by thermal loading of the waste. The question of ongoing diapirism in salt domes is a significant uncertainty at the present time.
6. Volcanism. Sites in rock such as tuff, basalt, or granite should be located to avoid potential volcanic activity. The age of volcanic

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activity at or near a site may be a tool for predicting future volcanism.

4.4 Physics and Chemistry

1. Rock Composition. The chemical and mineralogical composition of the host rock and surrounding rocks will strongly influence the radionuclide retardation characteristics of the various units.
2. Groundwater Composition. The chemical composition of groundwater is very important to the stability of the waste package and to radionuclide transport. The important factors include oxidation potential (Eh), acidity (pH), conductivity, and inorganic and organic species. Many of these factors must be determined in situ.
3. Groundwater Age. The age of groundwater in or near the repository layer will indicate the rate of potential radionuclide transport in the region around the repository and will aid in deducing the hydrologic history of the area.
4. Mechanical Properties (applicable to both short-term and long-term performance). These rock properties will determine the ability of the repository and surrounding layers to support the openings of shafts and the repository cavity. Included here are strength, plasticity, and the various moduli.
5. Thermal Properties. These rock properties determine the response of the medium to the thermal stresses presented by the waste. Conductivity, expansion coefficient and thermal alteration are important.
6. Retardation Potential. The capacity of the various rock units of the site, especially the aquifers, to retard by adsorption radionuclides

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carried in groundwater is a vital part of the isolation system. In situ measurement of retardation potential and permeability is essential.

7. Radiation Effects. It is important that the detrimental effects of radiation on the chemical, mechanical and thermal properties of the repository medium be known and accounted for.
8. Geothermal Gradient. For long-term performance, the natural increase in temperature with depth at the site must not be such that the additional heat generated by the emplaced waste could present a problem to containment. In the short term, the natural temperature must be low enough that proper ventilation for mining and emplacement operations is possible.
9. Dissolution. The repository layer (in the vicinity of the repository) must be secure from dissolution by groundwater during the isolation period. In addition, conditions must be avoided which might lead to breccia pipe or rubble layer formation, such as inadequately sealed boreholes or shafts. These problems are significant in bedded and domed salt repositories.
10. Alteration. Chemical alteration of rock along fractures, especially igneous rock such as basalt and granite, may alter the retardation capability of those rocks, and may also affect the flow of groundwater in those fractures.

4.5 Geohydrology

1. Repository Medium Hydrologic Characteristics. To contain radionuclides properly, the repository layer should be a significant barrier to fluid flow. A low permeability in the repository medium

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is necessary and, to be able to model long term effects, a knowledge of the porosity and dispersivity is essential.

2. Hydrologic Characteristics of Surrounding Rocks. In many sites, especially those in layered rock, containment is enhanced by the low permeability of the surrounding media. To model the system adequately, the hydrologic characteristics of these rocks must be understood.
3. Hydraulic Gradients, Regional and Local. Fluid movement away from a repository is controlled by hydraulic gradients. These should be of a magnitude and direction that will limit migration of radionuclides to the biosphere. Local gradient information is necessary for determining fluid movement in and out of the repository. Regional gradient information is necessary to determine direction and rate of movement to the potential water use locations.
4. Recharge and Discharge Rates and Locations. To understand the hydrology of the basin and of the repository site, the location of the recharge areas and rates must be known. To provide a pathway of sufficient length to adequately delay the movement of radionuclides to the biosphere, the discharge areas must be at a sufficient distance from the repository and the discharge rate must be sufficiently low.
5. Depth to Water Table. The location and fluctuation of the water table over time is especially significant for sites initially above the water table.
6. Aquifer Capacity. The useable capacity of the aquifers affects both the rate of radionuclide migration and the potential of the aquifer for groundwater withdrawal.

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7. Hydrological Transients. Many hydrological systems have not reached a steady state. They are still showing the effects of past climatic conditions. These effects must be understood to model future radio-nuclide migration.
8. Present and Projected Climate. Some understanding of the present and future climatic conditions is necessary to model the hydrology. Additional effort to understand the long term relationship between climate and hydrology may be necessary at some sites. Climate variation may cause changes in hydraulic gradients at or near the site.
9. Surface Hydrology. Surface hydrology and its potential modification are essential parts of the hydrologic model. The region's potential for flooding naturally or by man-made impoundments should be evaluated. Natural stream position changes which might alter the pathway from the repository to the biosphere should also be projected and evaluated.
10. Flow Characteristics. It is necessary to understand the type of flow through all of the rock units involved in the hydrologic model. Rocks like granite and basalt will exhibit fracture flow while tuff and shale may involve porous flow as well.
11. Interbed Characteristics. In bedded rocks like salt, there are often interbedded materials that have an adverse effect on the repository. Interbeds may provide a pathway by which water may enter or leave the repository. These must be evaluated to determine their impact on the performance of the repository.

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4.6 Geography

1. Site Ownership. The repository should be located at a site where the federal government has control over the surface and the subsurface over a substantial area.
2. Demography. Areas of current or projected high population density should be avoided.

4.7 Man-related Considerations

1. Borehole Density. Open or poorly sealed boreholes may provide fluid connections between aquifers or between the repository layer and an aquifer. This should be minimized by careful plugging of existing holes and drilling only a limited number of holes at or near the repository site. The existing borehole density is an important factor in site selection. A careful search for pre-existing boreholes is necessary.
2. Aquifer Use. Hydraulic gradients and fluid velocities increase when water is extracted from aquifers. Injection of fluids into aquifers will also alter hydraulic characteristics. The use or potential for use of aquifers in the area of concern near a repository should be limited.
3. Underground Activities. Disturbance of the sub-surface by mining, fluid production, disposal or storage may affect the containment capability of the strata containing or surrounding a repository. Past and present activities of this type in the area should be limited and the potential for future development should be small.

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4. Solution Mining. Some economic minerals are obtained by solution mining (salt, uranium and sulphur are examples). This activity could affect repository integrity and should be limited in the area of the repository (past, present and future).
5. Hydrocarbon Storage. Some rock types are suitable for hydrocarbon storage. Cavities in salt and porous strata capped by impermeable layers are examples. This activity could affect repository integrity and the area near the site should have a limited potential for such use.

5.0 Regulatable Elements of Modeling and Decision Analysis

An analysis process is a tool for making decisions with imperfect information and many options for site selection and repository design. The analysis process contains both inductive and deductive elements. The inductive elements involve mainly expert judgmental issues such as model selection, estimates of error, and process identification and selection. The deductive elements involve the formal conclusions which can be drawn by use of models. Both inductive and deductive elements operating on an information base are used in the determination of acceptable performance. The regulatable features of the analysis process are detailed below.

5.1 Inductive Methodology

1. Expert judgment. Expert judgment will play a significant role in the assessment of any site. Those areas in which expert judgment does play an important role must be clearly identified. Qualifications for experts must be clearly expressed.
2. Parameter estimation methodology. The estimation of model parameters from a set of measurements is an important issue. The estimation process which contains both inductive and deductive elements must be clearly defined and regulated.
3. Rules of Inference. The rules by which performance is inferred from measurement must be stated and regulated. For example, regulations are required to expressly state under which conditions worst case analysis, uncertainty analysis and fault tree analysis are to be used and what limits must be placed on their use. Techniques for the generation and analysis of scenarios must also have guidelines.

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5.2 Deductive Methodology

1. Codes and Models. The codes used in the evaluation process must be validated, tested, and accepted. Validation testing and acceptance procedures must be defined.
2. Performance Measure. The output format for conclusions must be clearly given. A uniform measure of repository performance must be agreed upon. Ranges of acceptable performance may then be specified.

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