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RADIOACTIVE WASTE ISOLATION IN SALT:

PEER REVIEW OF DOCUMENTS DEALING
WITH GEOPHYSICAL INVESTIGATIONS

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by

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FOREWORD

Documents are being submitted to the Salt Repository Project Office of the U.S. Department of Energy (DOE) by Battelle Memorial Institute's Office of Nuclear Waste Isolation to satisfy milestones of the Salt Repository Project of the Civilian Radioactive Waste Management Program. Some of these documents are being reviewed by multidisciplinary groups of peers to ensure DOE of their adequacy and credibility. Adequacy of documents refers to their ability to meet the standards of the U.S. Nuclear Regulatory Commission and the U.S. Environmental Protection Agency, as enunciated in 10 CFR Part 60 and 40 CFR 191, respectively, as well as those of the Nuclear Waste Policy Act of 1982. Credibility of documents refers to the validity of the assumptions, methods, and conclusions, as well as to the completeness of coverage.

Since late 1982, Argonne National Laboratory has been under contract to DOE to conduct multidisciplinary peer reviews of program plans and reports covering research and development activities related to siting and constructing a mined repository in salt for high-level radioactive waste. This report provides information to assist peer review panelists in their evaluation of the geophysical aspects of the site characterization plan being prepared for the site in Deaf Smith County, Texas, and related documents.

PREVIOUSLY PUBLISHED REPORTS IN THE SERIES

"RADIOACTIVE WASTE ISOLATION IN SALT"

ANL/EES-TM-242	Peer Review of the Office of Nuclear Waste Isolation's Geochemical Program Plan (Feb. 1984)
ANL/EES-TM-243	Peer Review of the Office of Nuclear Waste Isolation's Socioeconomic Program Plan (Feb. 1984) (revised July 1984)
ANL/EES-TM-246	Peer Review of the Office of Nuclear Waste Isolation's Plans for Repository Performance Assessment (May 1984)
ANL/EES-TM-254	Peer Review of the Office of Nuclear Waste Isolation's Reports on Preferred Repository Sites within the Palo Duro Basin, Texas (June 1984)
ANL/EES-TM-256	Special Advisory Report on the Status of the Office of Nuclear Waste Isolation's Plans for Repository Performance Assessment (Oct. 1983)
ANL/EES-TM-258	Peer Review of the Office of Nuclear Waste Isolation's Plan to Decommission and Reclaim Exploratory Shafts and Related Facilities (July 1984)
ANL/EES-TM-259	Peer Review of the Office of Nuclear Waste Isolation's Final Report on the Organic Geochemistry of Deep Groundwaters from the Palo Duro Basin, Texas (Aug. 1984)
ANL/EES-TM-260	Peer Review of the Texas Bureau of Economic Geology's Report on the Petrographic, Stratigraphic, and Structural Evidence for Dissolution of Upper Permian Bedded Salt, Texas Panhandle (Aug. 1984)
ANL/EES-TM-261	Peer Review of the Office of Nuclear Waste Isolation's Report on Functional Design Criteria for a Repository for High-Level Radioactive Waste (Aug. 1984)
ANL/EES-TM-262	Peer Review of the D'Appolonia Report on Schematic Designs for Penetration Seals for a Repository in the Permian Basin, Texas (Sept. 1984)
ANL/EES-TM-263	Peer Review of the Office of Nuclear Waste Isolation's Report on Multifactor Life Testing of Waste Package Materials (Sept. 1984)
ANL/ES-147	Rationale and Methodology for Argonne-Conducted Reviews of Site Characterization Programs (July 1985)

PREVIOUSLY PUBLISHED REPORTS IN THE SERIES

"RADIOACTIVE WASTE ISOLATION IN SALT" (Cont'd)

- ANL/EES-TM-290 Geochemistry of Brine in Rock Salt in Temperature Gradients and Gamma-Radiation Fields -- A Selective Annotated Bibliography (July 1985)
- ANL/EES-TM-292 Peer Review of Westinghouse Electric Corporation's Report on Reference Conceptual Designs for a Repository Waste Package (Oct. 1985)
- ANL/EES-TM-316 Peer Review of the Office of Nuclear Waste Isolation's Draft Report on an Issues Hierarchy and Data Needs for Site Characterization (Dec. 1986)
- ANL/EES-TM-319 Peer Review of the Office of Nuclear Waste Isolation's Report on a Multifactor Test Design to Investigate Uniform Corrosion of Low-Carbon Steel (Jan. 1987)
- ANL/EES-TM-320 Peer Review of the Golder Associates Draft Test Plan for In Situ Testing in an Exploratory Shaft in Salt (Jan. 1987)
- ANL/EES-TM-322 Peer Review of the Fluor Technology, Inc., Report and Position Paper Concerning Waste Emplacement Mode and Its Effect on Repository Conceptual Design (Feb. 1987)

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ACRONYMS

CDP	common depth point
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
EDBH	engineering design boreholes
EPA	U.S. Environmental Protection Agency
ESF	exploratory shaft facility
LSA4	Lower San Andres Unit 4
NWPA	Nuclear Waste Policy Act of 1982
NRC	U.S. Nuclear Regulatory Commission
SCP	site characterization plan
SRP	Salt Repository Project
THMC	thermal-hydrological-mechanical-chemical

RADIOACTIVE WASTE ISOLATION IN SALT: PEER REVIEW OF DOCUMENTS DEALING WITH GEOPHYSICAL INVESTIGATIONS

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L.D. McGinnis and R.H. Bowen

ABSTRACT

The Salt Repository Project, a U.S. Department of Energy program to develop a mined repository in salt for high-level radioactive waste, is governed by a complex and sometimes inconsistent array of laws, administrative regulations, guidelines, and position papers. In conducting multidisciplinary peer reviews of contractor documents in support of this project, Argonne National Laboratory has needed to inform its expert reviewers of these governmental mandates, with particular emphasis on the relationship between issues and the technical work undertaken. This report acquaints peer review panelists with the regulatory framework as it affects their reviews of site characterization plans and related documents, including surface-based and underground test plans. Panelists will be asked to consider repository performance objectives and issues as they judge the adequacy of proposed geophysical testing. All site-specific discussions relate to the Deaf Smith County site in Texas, which was approved for site characterization by the President in May 1986. Natural processes active at the Deaf Smith County site and the status of geophysical testing near the site are reviewed briefly.

1 INTRODUCTION

Argonne National Laboratory has been conducting peer reviews of contractor documents in support of the Salt Repository Project, a U.S. Department of Energy (DOE) program to site, design, construct, operate, and decommission a mined repository in salt for high-level radioactive waste.* Review of these documents requires the expert judgments of geoscientists who may not be especially familiar with this project. In addition to possessing a high level of specialized expertise and interpretive skill, these geoscientists must be cognizant of the relationship between governmental requirements and project activities. They must also be well acquainted with the peer review process, which is summarily described in the following paragraph.

*Appendix A is a glossary of specialized terms either used in this report or closely related to Salt Repository Project activities.

Upon receipt of a draft contractor document to be reviewed from the Salt Repository Project Office, Argonne constitutes a peer review panel whose members have expertise appropriate for the document. The written review comments of the panelists are compiled under the auspices of the panel chairman into an Argonne review report, a draft of which is forwarded by the Salt Repository Project Office to the contractor for its consideration. The contractor responds by drafting action statements that detail how the document will be revised in light of the comments. When the Argonne panel chairman, the Salt Repository Project Office, and the contractor are satisfied with the actions to be taken, each party signs a concurrence statement. Reaching concurrence on the action statements usually requires several iterations. The peer review process thus affords panelists the opportunity to influence activities related to the site characterization and related programs through the document revision process.

Because Argonne is conducting peer reviews of the site characterization plan (SCP) and related documents for the Deaf Smith County site in Texas, this report summarizes the essential features of the site, the important natural processes active there, and the status of geophysical investigations. It also covers the review of site test plans, aspects of the site selection process, and the adequacy of the expected geophysical program in terms of the regulatory framework.

Although this report is oriented toward geophysicists, much of the material about federal regulations should be helpful to other geoscientists participating in the peer review process. All panelists will be asked to evaluate the degree to which documents adhere to the complex requirements of the applicable regulations.

1.1 OVERVIEW OF SALT REPOSITORY PROJECT

A site in Deaf Smith County, Texas, was approved for site characterization by the President in May 1986. At design depth (750-800 m), the repository will have an area of approximately 900 hectares. The complex of tunnels and rooms will be accessed by vertical shafts. The host rock will be the Lower San Andres Unit 4 (LSA4) salt, which is a bedded salt of Permian age approximately 75 m thick.

During early phases of site characterization, an exploratory shaft facility (ESF) will provide access for testing and geophysical measurements. Following an operating period of approximately 50 years, the repository will be closed and sealed. Waste isolation will be achieved by a system of multiple barriers, both natural and engineered.

1.2 SITE CHARACTERIZATION

Following a schedule prescribed in the Nuclear Waste Policy Act of 1982 (NWPA, Public Law 97-425), the President approved in May 1986 three sites to be characterized for the first repository: a site in basalt on the Hanford Reservation in Washington; one in tuff adjacent to the Nevada Test Site; and one in bedded salt in the Palo Duro Basin in Deaf Smith County, Texas. Site characterization must precede final recommendation of

a site by the President. The following two paragraphs are excerpted from U.S. Department of Energy (1984, p. 47,717).

During site characterization, the DOE will collect detailed information on the geologic, hydrologic, and other characteristics that determine compliance with the siting guidelines requiring site characterization for their application. Standard geophysical tests and exploratory drilling from the surface will continue throughout site characterization. For subsurface investigations, exploratory shafts will be constructed to the depth at which a repository would be built. Limited subsurface excavations (tunnels and rooms) for testing purposes will be made in the host rock in the immediate vicinity of the shafts. The shafts will be large enough to allow people and test equipment to be transported from the surface to the rooms. The shafts, tunnels, and rooms will allow detailed study of the host rock, including lateral exploratory drilling. A variety of tests will be performed in these underground facilities, including, for example, measurements of in-situ stress and permeability and heat-transfer experiments. Every 6 months, the DOE will report to the NRC [U.S. Nuclear Regulatory Commission] and to the affected States and Indian tribes on the nature and the extent of the site-characterization activities and the information obtained from these activities.

In parallel with site characterization, the DOE will collect additional information about other aspects of the site. This activity, informally called site investigation, will be carried out in order to establish compliance with the guidelines that do not require site characterization (e.g., demographic, socioeconomic, and ecological characteristics) and to comply with the National Environmental Policy Act of 1969.

1.3 REGULATORY REQUIREMENTS AFFECTING SITE CHARACTERIZATION

Although federal regulations rigorously define the required specifications of candidate sites for a high-level radioactive waste repository, they also provide some flexibility. For example, geophysicists working for DOE or its contractors are free to select techniques and to specify data-acquisition and data-processing methods.

The main documents governing the Salt Repository Project are:

1. Nuclear Waste Policy Act of 1982 (Public Law 97-425) (1982).
2. *Disposal of High-Level Radioactive Wastes in Geologic Repositories; Licensing Procedures*, U.S. Nuclear Regulatory Commission, Code of Federal Regulations (CFR), Title 10, Part 60 (1983).

3. *Nuclear Waste Policy Act of 1982; General Guidelines for the Recommendation of Sites for the Nuclear Waste Repositories; Final Siting Guidelines*, U.S. Department of Energy, Code of Federal Regulations, Title 10, Part 960 (1984).
4. *Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Wastes; Final Rule*, U.S. Environmental Protection Agency (EPA), Code of Federal Regulations, Title 40, Part 191 (1985).
5. *Standard Format and Content of Site Characterization Plans for High-Level-Waste Geologic Repositories*, U.S. Nuclear Regulatory Commission, Regulatory Guide 4.17 (1982).

The remaining paragraphs in Sec. 1.3 are, for the most part, excerpts from these five documents, chosen for their applicability to peer review of SCPs and associated documents.

Site characterization plans submitted pursuant to NWPA are to include (Sec. 113[b][1][A][ii]):

. . .a description of such site characterization activities, including the following: the extent of planned excavations, plans for any onsite testing with radioactive or nonradioactive material, plans for any investigation activities that may affect the capability of such candidate site to isolate high-level radioactive waste and spent nuclear fuel, and plans to control any adverse safety-related impacts from such site characterization activities.

The second item (10 CFR 60) includes repository performance objectives and definitions critical to appropriate review of the geological and geophysical aspects of project documents. The documents to be reviewed will use the term "site characterization," which is defined as (Sec. 60.2):

. . .the program of exploration and research, both in the laboratory and in the field, undertaken to establish the geologic conditions and the ranges of those parameters of a particular site relevant to the procedures under this part. Site characterization includes borings, surface excavations, excavation of exploratory shafts, limited subsurface lateral excavations and borings, and in situ testing at depth needed to determine the suitability of the site for a geologic repository, but does not include preliminary borings and geophysical testing needed to decide whether site characterization should be undertaken.

Performance objectives (Sec. 60.111-60.113) are those technical criteria that must be met with reasonable assurance so that there will be no unreasonable risk to the health and safety of the public. These criteria consider the disruptive processes and events that might affect waste containment over the 1000 years following emplacement (e.g.,

deliberate or inadvertent human intrusion). One important performance objective is to provide for the retrieval of waste packages, "starting at any time up to 50 years after waste emplacement operations are initiated."

The third item (10 CFR 960) provides "...general guidelines for the recommendation of sites for repositories for the disposal of high-level radioactive waste and spent nuclear fuel in geologic formations." These guidelines are used during site selection, as required by NWPA, and are compatible with relevant EPA regulations (40 CFR 191). The guidelines establish performance objectives for a geologic repository system, define the basic technical requirements that candidate sites must meet, and specify how DOE will implement its site selection process.

The fourth document (40 CFR 191) contains postclosure requirements that apply to mined geologic repositories regulated by NRC. The following excerpts are from a summary of these requirements that was informally attached by EPA to the regulation:

1. The repository must be designed to provide a reasonable expectation (but not necessarily complete assurance), based on performance assessments, that the cumulative release of radionuclides to the accessible environment from all significant processes and events for 10,000 years after closure will (a) have a likelihood of less than one chance in 10 of exceeding specified limits (based on quantity of waste disposed of and type of radionuclide); and (b) have a likelihood of less than one chance in 1000 of exceeding 10 times the specified limits. . . . [The key words here are "release...to the accessible environment." Thinking must be directed toward understanding the geological media, including hydrogeologic pathways, that lie between the waste package and the accessible environment.]
2. The repository must be designed to provide a reasonable expectation that, for 1000 years after closure and assuming no disruption by human intrusion or the occurrence of unlikely natural events, the annual dose equivalent from the repository to any member of the public in the accessible environment will not exceed 25 mrem to the whole body or 75 mrem to any organ (except skin and cornea). [The key points here are related to natural events and accessible environment.]
3. The repository must be designed to provide a reasonable expectation that, for 1000 years after closure and assuming no disruption by human intrusion or the occurrence of unlikely natural events, the radionuclide concentrations averaged over any year in water withdrawn from a special source of ground water will not exceed certain specified limits or, if the waters already exceed those limits, will not be increased by more than those limits. A special source of ground water means Class I ground waters (as defined in the EPA Ground-Water Protection Strategy) [U.S.

Environmental Protection Agency, 1984] that are "near (less than 5 km) or within the controlled area, are currently used to supply drinking water to thousands of people, and are irreplaceable by a reasonable alternative. [Here the key areas include the controlled area and Class I groundwaters being less than 5 km horizontally from the controlled area.]

Among other things, the results of the site characterization program are to establish that the natural and engineered barriers will contain waste as required in 10 CFR 60. In particular, Sec. 60.113 stipulates that the geologic setting must be such that "pre-waste-emplacement groundwater travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1000 years or such other travel time as may be approved or specified by the Commission." This performance objective is being reviewed by NRC (1986) in light of 40 CFR 191, which defines "disturbed zone" (whose definition includes the term "controlled area") and "accessible environment" somewhat differently. (See App. A for an explanation of proposed changes in these definitions.)

Regulatory Guide 4.17 provides a standard format for preparation of SCPs. It includes discussions pertinent to geology and geophysics in Part C, Secs. 3, 4, 5, 6, 8, and 10.2.2.

1.4 SELECTING THE DEAF SMITH COUNTY SITE

The U.S. Department of Energy (1984) has divided the siting process into five phases: (1) screening, (2) site nomination, (3) site recommendation for characterization, (4) site characterization, and (5) site selection (recommendation for development as a repository). Geophysical testing is most applicable to phases 1, 2, and 4. The Deaf Smith County site is in phase 4, as are the sites in Nevada and Washington.

The screening process (phase 1) resulted in the identification by DOE of seven salt sites -- two salt domes in Mississippi, one salt dome in Louisiana, two sites in bedded salt in the Paradox Basin in Utah, and two sites in bedded salt in the Palo Duro Basin in Texas -- as being potentially acceptable in accordance with the guidelines in 10 CFR 960.

The nomination of the Deaf Smith County site in phase 2 proceeded according to the prescribed regulatory methodology, whereas the nominations of the sites in Washington (basalt) and Nevada (tuff) were governed by historical land use; that is, previous land use was considered as an alternative to site screening. Suitable repository sites on federal lands where radioactive materials were already present were identified by DOE. Because all of the sites had not been chosen according to established guidelines, the recommendation by the Secretary of Energy of sites for characterization, scheduled for 1984, was delayed, contingent upon a special review. The National Academy of Sciences (U.S. Department of Energy, 1986a) studied DOE's site selection methodology (U.S. Department of Energy, 1986b) and the first drafts of Chapter 7 of the environmental assessment (U.S. Department of Energy, 1984c), including comments on those drafts by the public.

Phase 3 was completed in May 1986, when the President, following the nomination of five sites by the Secretary of Energy, approved three sites for characterization, one of them being the Deaf Smith County site. In making the nominations, the Secretary of Energy had considered the provisions in the siting guidelines for diversity of hydrogeologic settings and diversity of rock types (U.S. Department of Energy, 1986a).

2 REVIEW OF SITE STUDY PLANS

Site characterization requires a suite of site study plans, which are to cover surface, underground, and environmental characterization (Baillieul, 1986). Underground studies will be conducted in the ESF, which may later be used as part of the repository if one is constructed at the site. The purpose of the plans is to describe in detail the tests and procedures discussed in Chapter 8 of the SCP, which is the site characterization program.

After reviewing Harrison et al. (1985) and this report, peer review panelists should be generally familiar with the formal guidelines and regulations of the Salt Repository Project and should be prepared to judge whether geophysical data-acquisition and data-processing needs have been properly identified. Reviewers will also be responsible for examining the performance objectives, performance issues, and conceptual models for the repository's systems and subsystems and for critiquing study plans as to their appropriateness for evaluating future repository performance. Issues that should drive the formulation of data-acquisition plans to satisfy data needs are identified in U.S. Department of Energy (1986d). Harrison et al. (1985, p. 22) present example questions, related to project issues, that reviewers might ask with regard to proposed studies. Section 3.2 of this report presents typical questions geophysicists might ask with respect to project issues.

Section 2.1 discusses NRC's rationale for the testing required of DOE, and Sec. 2.2 explores NRC's generic position on the geophysical tests identified in existing documents. Particular tests are not specified in any of these documents; however, specific performance objectives and issues are defined. Sections 2.3 and 2.4 cover the natural processes that figure prominently in the models being developed and the conditions that would eliminate a site from consideration if they were to be present.

2.1 NRC'S RATIONALE FOR THE TESTING REQUIRED OF DOE

Section 113(b) of NWPA requires DOE to include plans for on-site testing in its SCPs. In accordance with NWPA, NRC has published generic technical position documents that detail the kinds of in situ testing that NRC thinks should be included in the SCPs. The NRC documents do not divide the testing program into surface-based and underground test plans but instead refer to characterization studies as "in situ testing." The term "in situ" signifies "field" as opposed to "laboratory" studies and applies to portions of both the surface-based and underground test plans.

The U.S. Nuclear Regulatory Commission presents its rationale for "in situ" testing in the document entitled *Generic Technical Position on In Situ Testing during Site Characterization for High-Level Nuclear Waste Repositories* (U.S. Nuclear Regulatory Commission, 1985). The document states (pp. 7-8):

The in situ [field] testing program must be site specific to account for: (i) local geologic conditions, (ii) analytical methods and models chosen for use at the site, and (iii) key issues found relevant to

performance of the selected repository design. However, certain features are common to all in situ testing programs and should be addressed explicitly in the rationale as follows:

- (1) All relevant issues requiring resolution by in situ testing and measurements;
- (2) The information needs for the license application (identified on the basis of 10 CFR Part 60 requirements and the level of uncertainty in predicting the performance of the repository);
- (3) The availability of existing tests to provide all the information needed;
- (4) The capabilities and limitations of available tests and measurement methods;
- (5) The need, if any, to develop new tests;
- (6) The effects of testing on long term repository performance;
- (7) The extent of the underground test facility required to assess host rock variability properly and to assess the effect of that variability on design and performance;
- (8) The extent of the underground facility needed in order to minimize or avoid interference among tests;
- (9) The sufficiency of subsurface geologic mapping, geophysical testing, and core drilling to assess the characteristics of the host rock and the variability of its properties;
- (10) The representativeness of the in situ test location compared to the entire volume of rock, that must be assessed in determining compliance with the U.S. Environmental Protection Agency limits for releases to the accessible environment;
- (11) The basis for selection of a particular scale and duration of testing;
- (12) Justification for conducting or not conducting coupled/interactive (THMC) [thermal-hydrological-mechanical-chemical] tests;
- (13) Extent of credit taken for the performance of important components of the barrier system, engineered and natural;

- (14) The sufficiency (amount, scale and duration) of geological, hydrological, geomechanical, geochemical, thermal, and coupled/interactive testing, to make findings on compliance with the performance objectives on a scale that is sufficient to realistically represent the inhomogeneities and discontinuities of the rock being tested; and
- (15) Description of the manner in which data from surface borehole testing and laboratory testing on small-scale samples will be integrated with the in situ test results.

The U.S. Nuclear Regulatory Commission describes the content of the in situ test plan as follows (p. 8):

The in situ test plan should identify all important parameters, classify them according to their relative importance, and document their potential variability and its influence on design/performance. The plan should be flexible to accommodate new issues that might develop during site characterization. The in situ test plan should include such components as: the tests to be performed during site characterization needed to characterize the host rock before construction and waste emplacement, and to determine the response of the host rock and engineered components to construction and waste emplacement activities; criteria for determining sufficient number of tests; schedules and duration of various tests and their relationship to site selection, repository design, and licensing schedules; types of analyses to be applied to the test data and the validity of these analytical methods; and the quality assurance programs under which testing and analyses will be conducted.

2.2 GEOPHYSICAL TESTS IDENTIFIED IN EXISTING DOCUMENTS

Several DOE and NRC documents identify in a general way the tests or types of tests that should be part of the data-acquisition plans presented in the SCP for the Deaf Smith County site. These documents include the environmental assessment (U.S. Department of Energy, 1986c) and the document entitled *Generic Technical Position on In Situ Testing during Site Characterization for High-Level Nuclear Waste Repositories* (U.S. Nuclear Regulatory Commission, 1985). The following excerpts concerning the geophysical tests to be undertaken during site characterization are from U.S. Department of Energy (1986c, pp. 4-8 to 4-16):

1. **Geophysical Logging.** Downhole geophysical logging is routinely performed after wells are drilled and sometimes at intermediate stages. Logging involves lowering measuring tools down the hole and recording data as the tools are withdrawn. A suite of geophysical logs will be run in most deep boreholes; not all boreholes at multiple well sites will be logged with the entire suite of logs.

2. *Microseismic Monitoring.* Seismograph records provide data on ground motion which will be utilized in design of the repository surface and subsurface facilities, as well as for assessment of tectonic stability. It is anticipated that some of the existing 16 seismograph stations will be relocated or reconstructed (placed deeper in the ground) to improve network areal coverage and sensitivity. The existing microearthquake network will also be supplemented by installation of an additional 10 to 15 seismograph stations.

3. *Seismic Reflection and Refraction.* Common depth point (CDP)* seismic data will be obtained to evaluate selected subsurface structural features in the area. Two CDP surveys will pass near the two EDBH [engineering design borehole] locations. High resolution surveys may also be run over playas as part of overall playa investigations.

Four short refraction surveys, each about 0.8 kilometer (0.5 mile) long, will be run in the vicinity of the exploratory shaft facility (ESF) to determine shallow seismic velocities for engineering purposes.

4. *Three-Dimensional Seismic Reflection.* The 3-D seismic reflection survey will be used to collect data that will define the site geologic structure and demonstrate continuity of rock units between boreholes for characterization and design purposes. The 3-D survey will be conducted over approximately 26 square kilometers (10 square miles).

5. *Potential Field Surveys.* Regional gravity and magnetic data for the region are being reviewed. New high-resolution surveys will be run over the site and other selected areas, if it is determined there are data gaps, structures, or lateral data variations which require investigation. Electrical surveys, such as resistivity profiles or soundings, may be conducted to investigate shallow geologic features. Various grids may be run over the area to be investigated.

6. *Surface Geologic and Topographic Mapping.* The objectives of this activity are to produce topographic and surficial geologic maps of the surface facilities areas. . . and site access routes. Detailed maps are required for grading, site drainage, and access road design. Topographic control will be established by a small survey crew. Geologic mapping may involve shallow-auger holes or test pits. Detailed surface mapping will be conducted in selected areas to investigate faulted or potentially faulted areas.

7. *Borehole Search and Characterization.* A search will be conducted for unrecorded wells within the site vicinity. Those that could have a potential impact on the stability of the repository may need to be

*Also referred to as "common reflection point" seismic data.

reentered for testing and evaluation by methods similar to those described [elsewhere]. No such boreholes are thought to exist at the site. Search techniques may include review of state and local drilling records, review of historic newspaper accounts and aerial photographs, door-to-door surveys, discussions with various historical societies, and possible walking of the site with hand-held metal detectors. If an abandoned well is discovered, it may be necessary to excavate the site. Borehole plugging may require disturbance of a few acres over a period of up to 6 months.

8. *Engineering Design Boreholes (EDBH)*. This activity results in the collection of stratigraphic and geotechnical data at each of the two exploratory shaft sites. The EDBHs will be sampled continuously from ground surface to approximately 61 meters (200 feet) below the repository horizon.

9. *Exploratory Shaft Facility (ESF)*. The ESF is to be constructed to gain access to the potential repository salt horizon and to perform in situ tests for site characterization. . . . The facility will include two shafts, a production shaft and a service shaft. The service shaft is required for personnel safety. . . and ventilation. Both shafts will be constructed by conventional shaft sinking techniques and will have a finished diameter of 3.6 meters (12 feet). The underground excavation totals approximately 1,652 linear meters (5,420 linear feet) to support testing.

The above list is not comprehensive, nor are the tests explained in detail. The tests themselves and the parameters to be measured are subject to change and must be reviewed in the context of the entire program.

2.3 NATURAL PROCESSES AND EVENTS IMPORTANT IN THE MODELS BEING DEVELOPED TO CHARACTERIZE THE DEAF SMITH COUNTY SITE

Formal geological and geophysical models of proposed repository sites were prepared for the environmental assessments and are being continually modified as new data become available. The natural processes being incorporated into such models, because of their importance to waste isolation, and therefore to repository performance, are discussed briefly in Secs. 2.3.1-2.3.7, with particular reference to the Deaf Smith County site. Section 2.3.8 discusses events too improbable or unimportant to be included in such models.

The Deaf Smith County site is located in the north-central part of the county in the Southern High Plains of the western Texas Panhandle (see Fig. 1). More specifically, it is located near the northwest axis of the Palo Duro Basin on the southwestern flank of the Amarillo-Wichita uplift, which separates the Palo Duro Basin from the much deeper Anadarko Basin to the north. The basin is marginal between the Texas craton (Flawn, 1956) and the southern flank of the southern Oklahoma aulacogen (Ham et al., 1964; Burke and Dewey, 1973; Hoffman et al., 1974; Wickham, 1978).

FIGURE 1 Regional Tectonic Map and Location of the Deaf Smith County Site
(Source: Adapted from U.S. Department of Energy, 1986c)

The asymmetrical Palo Duro Basin has in its deepest portion an elongate trough in which 3000-3300 m of sediment accumulated. The 600-m pre-Permian section consists of a basal Cambrian marine sandstone, Cambro-Ordovician shallow-shelf carbonates, Mississippian carbonates, and Pennsylvanian clastic rocks and carbonates. The 2000-m Permian section comprises clastics, evaporites, and carbonates. The unit recommended for the repository is the LSA4 salt of Permian age, the top of which lies 720 ± 50 m below the surface (see Fig. 2 and App. B).

2.3.1 Faults

Although direct evidence of faulting more recent than Permian has not been found in the Palo Duro Basin, the historical earthquake record indicates that microseisms (and therefore minor faulting) occur in localized areas of the upper crust. Recent surface faulting has been reported at the Meers fault (see Fig. 1) in Oklahoma, approximately 310 km to the east of Deaf Smith County. This fault lies within the area of the Amarillo-Wichita uplift.

ERA	SYSTEM	SERIES	GROUP	FORMATION
CENOZOIC	QUATERNARY			RECENT FLUVIAL AEOLIAN AND LACUSTRINE DEPOSITS
	TERTIARY			OGALLALA AND LACUSTRINE DEPOSITS
MESOZOIC	CRETACEOUS	COMANCHE	WASHITA FREDRICKSBURG	
			TRINITY	
	TRIASSIC		DOCKUM	TRUJILLO (Santa Rosa) TECOVAS
PALEOZOIC	PERMIAN	OCHOA		DEWEY LAKE (Quartermaster) ALIBATES
		GUADALUPE	ARTESIA (WHITEHORSE)	SALADO - TANSILL
				YATES
				SEVEN RIVERS
				QUEEN-GRAYBURG
			PEASE RIVER	SAN ANDRES (BLAINE)
		LEONARD	CLEAR FORK	GLORIETA
				UPPER CLEAR FORK
				TUBB
				LOWER CLEAR FORK
		WICHITA	RED CAVE	
		WOLFCAMP		
	PENNSYLVANIAN	VIRGIL	CISCO	
		MISSOURI	CANYON	
		DES MOINES	STRAWN	
		ATOKA	BEND	
MORROW				
MISSISSIPPIAN	CHESTER			
	MERAMEC			
	OSAGE			
ORDOVICIAN	CANADIAN	ELLENBURGER		
CAMBRIAN		UNNAMED SANDSTONE		
	PRECAMBRIAN			

Explanation

~~~~~ Unconformable Boundary

Boundary in Dispute

() Formation Name in Outcrop

Stratigraphic Column of the Palo Duro Basin

FIGURE 2 Stratigraphic Column for the Palo Duro Basin (Source: U.S. Department of Energy, 1986c)

2.3.2 Earthquakes

The earthquakes that occur in the Texas Panhandle are associated with the Amarillo Uplift (see Fig. 1). Nuttli and Herrmann (1978) place the Palo Duro Basin and the Amarillo uplift in the "residual events" and "Wichita-Ouachita" zones, respectively. Herrmann (1979) provides a rough hypocentral depth of 10 km for earthquakes in the Texas Panhandle. These depths are based on spectral characteristics of long-period surface waves for the February 15, 1974, earthquake of magnitude 4.5 on the Oklahoma-Texas border (36.5°N, 100.69°W). The maximum intensity reported in the 100-year historical record for the region is a Modified Mercalli VI. Nuttli and Herrmann (1978) estimate that the maximum credible earthquake on the Amarillo uplift, which is 55-80 km from the Deaf Smith County site, would be of magnitude 6.3. It is estimated that a maximum magnitude earthquake of 5.3. could occur on any fault in or beneath the Palo Duro Basin. For a summary of known seismicity in the Deaf Smith County region, see U.S. Department of Energy (1986c, pp. 3-76 to 3-82).

Although the Palo Duro Basin is located in an area of historically low seismicity, the proximity of the Meers fault of Recent age requires that special attention be paid to the potential for natural seismic events.

2.3.3 Volcanic Rocks

Volcanic rocks, ranging in age from Late Cretaceous to Quaternary, occur in northeastern New Mexico (U.S. Department of Energy, 1986c). Quaternary volcanics have been found in Union County, with the youngest flows dating from between 10,000 and 4400 B.P., as determined by radiocarbon dating at archeological sites. The nearest Late-Tertiary/Quaternary volcanics occur 160 km northwest of Deaf Smith County.

2.3.4 Hydrogeology

The groundwater regime beneath the Southern High Plains in the Texas Panhandle consists of three major hydrogeologic units (U.S. Department of Energy, 1986c). The uppermost unit is an unconfined aquifer consisting of the Ogallala Formation and the Dockum Group, often called the "High Plains aquifer" or the "Ogallala aquifer." The middle unit is an aquitard consisting of 1500-1800 m of shales and evaporites lying below the High Plains aquifer. The repository horizon is near the middle of this aquitard. Lying below the aquitard is the lower hydrogeologic unit, a briny aquifer consisting of much older carbonate and clastic rocks.

Recharge to the High Plains aquifer is principally from precipitation collected in playa lakes (Bentley, 1981). Its most significant discharge results from pumping. The deep brine aquifer is believed to be recharged by lateral groundwater infiltration, possibly from units cropping out in eastern New Mexico. No surface discharge from this latter aquifer has been identified; however, such discharges may occur in areas to the east, in Oklahoma.

The Pliocene Ogallala Formation is an important groundwater source, particularly for irrigation purposes. Deep flow in basin rocks is downward through the aquitard (Bassett et al., 1981). Present rates of vertical dissolution of San Andres salt are unknown beneath the site, although there is evidence of dissolution in both the central Palo Duro Basin beneath the High Plains and near the caprock escarpment.

Although flow rates into or out of the basin are not known, the presence of a downward hydraulic gradient in deep basin rocks suggests that the path taken by groundwater in traveling from the disturbed zone to the accessible environment will be long.

2.3.5 Sedimentation and Denudation

The upper sedimentary unit blanketing the Texas Panhandle is the Ogallala Formation, which was deposited 3.5 ± 0.2 million years ago. The Ogallala Formation is composed of fine to coarse gray sand and silt, with some gravel and red or yellow clay (U.S. Department of Energy, 1986c). The unit is unconsolidated except for several 1-2-m caliche layers in its uppermost portion. The sediments were derived from highlands uplifted northwest of Deaf Smith County and were deposited by rapidly flowing streams. The maximum thickness of the Ogallala in Deaf Smith County is 130 m.

Since Ogallala deposition, the High Plains area has been subjected to regional denudation, stream incision, and headward erosion and dissolution along the eastern and western caprock escarpments, as well as along the valley walls of streams and rivers, resulting in more than 300 m of topographic relief. About 6 m of Quaternary and Recent sediments is found along the valley floors. Present denudation rates are believed to average about 90 cm per thousand years. Headward erosion, together with dissolution of the uplands and sedimentation in the valley floors, continues to the present time. Headward erosion of the caprock escarpment is estimated at 100-200 m per thousand years. Future erosion and dissolution rates will depend primarily on future climates. Glacial epochs and concurrent pluvial cycles in the Southwest will result in decelerating erosion (because of vegetative cover), whereas interglacial periods and associated dry periods, as at present, will result in accelerating erosion. Regional vertical dissolution has in places produced subsidence over the High Plains of as much as 60 m.

2.3.6 Epeirogeny

Epeirogeny here refers to broad uplift relative to sea level since deposition of the Fredericksburg Group in Cretaceous time. A major uplift of approximately 1000 m associated with the Laramide episode to the northwest and tilt to the southeast occurred at the end of Fredericksburg time, as indicated by the presence of a major unconformity between the Fredericksburg Group and the Ogallala Formation (U.S. Department of Energy, 1986c). Uplift occurred over 50-60 million years. Since deposition of the Ogallala, the land surface in the High Plains has been lowered by denudation and dissolution by about 270 m. Stream integration suggests a lack of significant (and recent) active uplift.

2.3.7 Climate

Bloom (1983) hypothesizes that the end of the present interglacial period should occur within the next 10,000 years. However, human modifications of climate could delay or accelerate the onset of the next ice age. Therefore, the results of modeling anthropogenic modifications of climate should be monitored, with the most credible of these results used to estimate the effects of human-induced warming or cooling of the atmosphere on the onset of the next glaciation. Of the many environmental effects that could occur, the change from groundwater recharge to discharge would be the one that would most affect the Palo Duro Basin.

2.3.8 Improbable or Unimportant Events

Some natural processes or events are considered to have little significance for the site characterization process because they would be so unlikely to occur or because their consequences would be unimportant. Among these are small seismic events caused by failure of a geomorphic feature. Although dissolution-related collapses might occur at the surface, the amount of energy released would not affect repository integrity, particularly considering the distances expected from the repository to potential collapse structures in the Palo Duro Basin. Also, because of the anticipated integrity of the repository host rocks, it is highly improbable that collapses within the confines of the controlled area would directly affect the repository.

Also among these are extreme weather events, such as tornadoes, hurricanes, and blizzards. None of these would significantly affect the postclosure integrity of a repository because they are surface events of short duration.

2.4 DISQUALIFYING CONDITIONS

A disqualifying condition is defined in 10 CFR 960 (Sec. 960.2) as "a condition that, if present at a site, would eliminate that site from further consideration." A site may be disqualified at any time during the siting process if the evidence supports a finding by DOE that a disqualifying condition exists. Disqualifying conditions include (Sec. 960.4):

1. . . .The prewaste-emplacement groundwater travel time from the disturbed zone to the accessible environment is expected to be less than 1000 years along any pathway of likely and significant radionuclide travel.
2. . . .Site conditions do not allow all portions of the underground facility to be situated at least 200 m below the directly overlying ground surface.
3. . . .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.

4. . . .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.
5. . . .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.
6. . . .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.

Geophysical testing may help to define some of the above conditions. Test plans to establish the presence and configuration of factors unfavorable to containment will be formulated by DOE.

3 GEOPHYSICAL PROGRAM AT THE DEAF SMITH COUNTY SITE

Developing and conducting geophysical programs that can best assist in site characterizations will require the considered judgments of specialists who are able to synthesize performance objectives, geophysical methodologies, and test limitations. Wynn (1986) states that "characterization of potential sites requires geophysicists to alter their usual mode of thinking; no longer are anomalies being sought, as in mineral exploration, but rather their absence." The Salt Repository Project Office and outside contractors will need to recognize that the standard geophysical methods are limited and that the judgments of contractors and peer reviewers will have to be meshed with project performance objectives and issues. Rigorous program planning, implementation, peer review, and quality assessment activities are needed to keep the decision making with regard to geophysical applications within the regulatory framework.

3.1 STATUS OF GEOPHYSICAL DATA ACQUISITION

Although some regional-gravity, aeromagnetic, and seismic-reflection data were available at the time the Deaf Smith County site was approved for site characterization, the Salt Repository Project Office decided that additional seismic-reflection information would be needed for decision making before site characterization. Approximately 280 km of seismic-reflection profiling data for Deaf Smith County have already been acquired (see Fig. 3). However, none of the existing data were acquired directly over the site. The data are far less detailed than the site-specific data that will be required for site characterization. Most of the acquired data are proprietary. In most cases, the specifications were not designed to maximize reflection quality for deep structures having earthquake or tectonic significance; however, they were adequate for providing information on regional, shallow structures.

Regional geophysical data, including gravity and aeromagnetic data, have been collected but have not been analyzed and interpreted specifically for Deaf Smith County. The following site-specific studies are planned: three-dimensional seismic reflection, seismic refraction, side-looking radar, microseismicity, resistivity, induced polarization, electromagnetics, and borehole geophysics. Regional and site-specific data will be evaluated with respect to Salt Repository Project guidelines.

The status of geophysical data acquisition in the Palo Duro Basin was the subject of an NRC/DOE meeting in Columbus, Ohio, in 1985 (see App. C). The geophysical data available at that time consisted mostly of borehole logs and seismic-reflection surveys related to oil exploration. However, some seismic-reflection data emphasizing resolution at depths of 600-1800 m had been obtained as part of screening activities specifically connected with repository site selection. The available data are limited and inherently uncertain with regard to detailed structural analysis, both for strata near the surface as well as for basement rocks. Some of the available seismic-reflection data and remote-sensing imagery have not yet been fully utilized. Participants at the meeting recommended that the existing data set be integrated into a comprehensive whole to include:

FIGURE 3 Test Wells and Seismic-Reflection Profiles of the Central Palo Duro Basin (Source: U.S. Department of Energy, 1986c)

1. A conceptual regional tectonic model to evaluate various structural interpretations.
2. A geologic model derived from gravity and magnetic data.
3. Resolution of difficulties in identifying the basement horizon.
4. Reevaluation of regional stress fields.

The U.S. Nuclear Regulatory Commission argued that expanded coverage with seismic-refraction profiling may provide useful information concerning lateral and vertical variations in velocity values. Such information can be used for locating exploratory drill holes, studying site hydrogeology, planning seismic-reflection lines, and evaluating shallow-reflection anomalies. Dual geophysical programs, particularly with respect to reflection profiling, may be desirable in certain areas to provide both shallow and deep structural data. Electrical and electromagnetic surveys should be used to resolve structural as well as hydrogeologic concerns.

A comprehensive geophysical program is planned for exploring in more detail the sedimentary section, the configuration of the basement, and the regional tectonic setting of the Deaf Smith County site. Additional specific programs will include (Ferrigan, 1986):

1. Three-dimensional seismic reflection coverage over a 23-km² area centered over the site.
2. Regional seismic-reflection, common-depth-point lines oriented north-south to investigate potentially anomalous features in a regional context.
3. High-resolution reflection/refraction seismic measurements over the exploratory shaft.
4. High-resolution seismic-reflection profiles over lineaments detected on side-looking radar.
5. Expansion of the microseismic network from 16 to 30 stations.
6. Acquisition of potential field data including magnetics, gravity, resistivity, and induced polarization.
7. Drilled suites of boreholes for borehole geophysical measurements within a 23-km² area centered over the shaft, with no holes into the proposed repository, except for one hole into the centerline of each of the two exploratory shafts.
8. Acquisition of subsurface geophysical data, including radar, acoustics, and other measurement data not yet specified.

Upon completion of surface and underground tests and upon review of the testing and the results by peer review panels, additional studies may be recommended.

3.2 ADEQUACY OF THE GEOPHYSICAL DATA-ACQUISITION PROGRAM IN LIGHT OF THE REGULATORY FRAMEWORK

The geophysical data-acquisition program briefly described in Sec. 3.1 does not contain the detailed specifications that would permit the adequacy of each geophysical method relative to the information needs derived from performance objectives and issues to be fully assessed or for conceptual models to be fully tested. To implement the DOE geologic repository program, expert professional judgment in the form of NRC/DOE review or contract teams will be brought to bear on the selection and design of an array of geophysical measurements for use in the study of stratigraphy, structure, and tectonics at the Deaf Smith County site (see App. D).

The recommended geophysical studies must be keyed to performance objectives and issues. For example, high-resolution seismic-reflection studies have the greatest potential for examining sedimentary layering and offsets caused by faulting that may be associated with anomalously high groundwater flow; however, as explained in App. C, a seismic-reflection study may prove useless without carefully designed and monitored data-acquisition specifications. In evaluating the appropriateness of surface-based testing specifications in relation to performance objectives and issues, peer review panelists should keep the following questions in mind:

1. Is a three-dimensional seismic-reflection study of the far field necessary to define the tectonic setting of the near field?
2. What array geometry for seismic-refraction and seismic-reflection data acquisition is best suited to define the stratigraphy, structure, and other geologic characteristics of the rocks surrounding the repository?
3. What digital sampling frequency (rate) is necessary to eliminate aliasing bias in reflection signals from thin, bedded salt and associated carbonate and anhydrite sedimentary layers at depths of several hundred meters?
4. What should the receiver frequencies and geophone group configurations be to establish subsurface correlations at the approximate depth of the repository?
5. Are there potential reflectors (e.g., crystalline basement) that should be known in some detail to detect fault lineaments that might pose reactivation hazards?
6. Should the energy source for seismic-reflection data acquisition be explosives, or something else?

7. To eliminate problems with noise or statics, should the seismic-reflection energy source be at the surface or at depth?

Examples of equally important, but less narrowly focused, questions concerning surface-based geophysical testing are:

1. Have contractors considered the adequacy of available regional gravity and magnetic data sets (see App. C), which are essential to establishing models of the tectonic framework and to understanding possible earthquake source zones in the repository region?
2. Have contractors taken into account the comprehensiveness of testing and the complementary nature of multiple geophysical measurements in establishing unique solutions to geological problems, while considering cost effectiveness?
3. Have proper steps been taken to verify and evaluate sophisticated data-processing techniques and interpretations?
4. How will recommendations for additional work be handled in the event the original tests are inadequate or subsurface excavation uncovers unforeseen hazards to waste containment?

This small sample of questions should guide panelists in formulating their concerns regarding geophysical studies. To further aid them in their assessments of repository documents, evaluations of geophysical methods for four geological environments are given in Tables D.1-D.4 in App. D. In Table D.2, high marks are given for site-specific data acquisition to seismic-reflection experiments and borehole logging. Panelists should consider whether the data resulting from a particular activity will provide adequate information on the presence of deep faults and structures in the crystalline basement, both locally and regionally. Panelists should also decide whether gravity and magnetics should be given the same high marks for faulted structures in the crystalline basement that might be earthquake source zones.

No matter how carefully data-acquisition specifications are constrained, some geological targets will not be completely defined because of inadequacies in geophysical techniques. Factors that may have considerable bearing on fluid flow, such as microfracture sets and elastic veins in salt, or on shaft and tunnel construction, such as gas or liquid inclusions, may not be identifiable using the proposed density or techniques of geophysical data acquisition. Experiments to determine the adequacy of geophysical tests for developing precise geologic models will need to be conducted.

The decision-making process related to geophysical testing should be sufficiently flexible to respond effectively to broad performance objectives and issues. Such flexibility is advantageous -- a broad mandate is afforded to evaluate proposed tests, recommend alternatives, and meet mandated goals involving program costs and schedules.

4 FINAL REMARKS

Numerous federal reports, regulations, and guidelines governing mined geologic disposal of high-level radioactive waste have been published over the last several years. Since passage of NWPA, the regulatory framework has been further developed and modified by DOE, NRC, and EPA into a comprehensive body of guidelines covering all aspects of the proposed geologic repository. This report summarizes the status and direction of geophysical activities for the Deaf Smith County site and relates that information to the regulatory framework.

Reviewers of the SCP and related documents must remain aware that the Salt Repository Project is constantly evolving. For example, DOE, NRC, and EPA continually update their documents to accommodate new findings or to resolve contradictions. A case in point is the action by NRC to amend 10 CFR 60 to eliminate differences between 10 CFR 60 and the final EPA rule 40 CFR 191. Although actions of this type will not usually affect decision making with respect to the geophysical aspects of the project, panelists may need to know about them. The revisions sometimes involve changes to important definitions like "accessible environment," "disturbed zone," and "controlled area."

Site characterization will be followed by site selection. As required by Sec. 114(a) of NWPA, the first step of site selection is for the three sites to be compared in an environmental impact statement. The performance assessment part of this analysis will include a prediction of the effects of the repository system, both during the time it is operational and after it has been sealed. The response of the repository to conditions that might affect its performance (e.g., natural events and processes, human actions, and interactions between the emplaced waste and the repository) will be assessed. This performance assessment will require the detailed information obtained during site characterization.

Before preparing the draft environmental impact statement, DOE will hold a meeting near each site to be advised on the issues that should be addressed. When completed, the draft environmental impact statement will be available for public comment. After the final environmental impact statement is prepared, the Secretary of Energy will recommend one of the sites for development as a repository. If the President approves the recommendation, he will recommend the site to Congress. The state in which the site is located may submit, within 60 days, a notice of disapproval to Congress. This disapproval prevents use of the site unless Congress passes a joint resolution approving the President's recommendation within the next 90 days of continuous session.

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APPENDIX A

GLOSSARY

APPENDIX A

GLOSSARY*

Accessible Environment -- The atmosphere, land surfaces, surface waters, oceans, parts of the lithosphere that are beyond the controlled area. . . (40 CFR 191.12(k)).[†]

Aquifer -- A body of rock that is sufficiently permeable to yield significant quantities of water to wells and springs (10 CFR 960.2).

Aquitard -- A body of rock that retards but does not prevent the flow of water to or from an adjacent aquifer; a leaky confining bed.

Barrier -- Any material or structure that prevents or substantially delays the movement of water or radionuclides (10 CFR 960.2).

Candidate Site -- An area, within a geohydrologic setting, that is recommended by the Secretary of Energy under Sec. 112 of the Nuclear Waste Policy Act of 1982 for site characterization, approved by the President under Sec. 112 of the Act for characterization, or undergoing site characterization under Sec. 113 of the Act.

Characteristic -- Aspect of ground or environment describing repository site, and being either quantitative ("parameter") or qualitative ("factor").

Characterize -- Describe the set of "characteristics," based on testing results or measurement.

Characterization -- The collecting of information necessary so as to characterize the site.

Conceptual Design -- The formative stage in the design of a facility. It develops project scope to satisfy program needs, operating needs, and statutory requirements; ensures project feasibility, and attainable technical performance levels; identifies and quantifies any project risks; and, develops a reliable cost estimate and a realistic performance schedule.

*Listed items are reproduced verbatim from a glossary included in the *Draft Test Plan for In Situ Testing in an Exploratory Shaft in Salt*, prepared by Golder Associates for Battelle Memorial Institute, Office of Nuclear Waste Isolation, Columbus, Ohio, pp. 121-152.

[†]Section 60.2 of 10 CFR 60 has been changed to read "all of the lithosphere" rather than "parts of the lithosphere" (U.S. Nuclear Regulatory Commission, June 19, 1986, *Disposal of High-Level Radioactive Wastes in Geologic Repositories; Conforming Amendments (proposed rule)*, Code of Federal Regulations, Title 10, Part 60, Fed. Reg., 51[118]:22,288-22,301).

Conceptual Model -- A physical description of a system devised to show property variations as based on field and laboratory measurements and best technical judgments.

Containment -- The confinement of radioactive waste within a designated boundary (10 CFR 60.2, 10 CFR 960.2).

Controlled Area -- A surface location, to be marked by suitable monuments, extending horizontally no more than 10 km 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 restricted following permanent closure (10 CFR 60.2, 10 CFR 960.2).*

Disturbed Zone -- That portion of the controlled area, excluding shafts, whose physical or chemical properties are projected to change permanently 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 the geologic repository (10 CFR 960.2).

Emplacement (as related to waste management) -- The act of placing containerized waste in a prepared position.

Engineered-Barrier System -- The man-made 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 canisters, materials placed over and around such canisters, any other components of the waste package, and barriers used to seal penetrations in and into the underground facility (10 CFR 960.2).

Environmental Assessment -- The document required by Sec. 112(b)(1)(E) of the Nuclear Waste Policy Act of 1982 (10 CFR 960.2).

Environmental Impact Statement -- The document required by Sec. 102(2)(C) of the National Environmental Policy Act of 1969. Sections 114(a) and 114(f) of the Nuclear Waste Policy Act of 1982 include certain limitations of the National Environmental Policy Act requirements as they apply to the preparation of an environmental impact statement for the development of a repository at a characterized site (10 CFR 960.2).

*The definition of "controlled area" in 40 CFR 191 is more restrictive than that in 10 CFR 60; therefore, the definition in Sec. 60.2 of 10 CFR 60 has been changed to "(1) a surface location, to be identified by passive institutional controls, that encompasses no more than 100 km² and extends horizontally no more than 5 km in any direction from the outer boundary of the underground facility, and (2) the subsurface underlying such a surface location" (U.S. Nuclear Regulatory Commission, June 19, 1986, *Disposal of High-Level Radioactive Wastes in Geologic Repositories; Conforming Amendments (proposed rule)*, Code of Federal Regulations, Title 10, Part 60, Fed. Reg., 51[118]:22,288-22,301).

Exploratory Shaft Facility -- Consists of exploratory shafts, extending from the surface to the repository horizon, possibly with test stations at various depths, and an underground test facility consisting of appropriate tunnels and test rooms at the horizon.

Facility -- Any structure, system, or system component, including engineered barriers, created by the U.S. Department of Energy to meet repository performance or functional objectives (10 CFR 960.2).

Far Field -- The geosphere, hydrosphere, and biosphere outside the thermally influenced area of a repository.

Geologic Repository -- A system, requiring licensing by the U.S. 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 (10 CFR 960.2).

Guideline -- A statement of policy or procedure that may include, when appropriate, qualifying, disqualifying, favorable, or potentially adverse conditions as specified in the "guidelines" (10 CFR 960.2).

High-Level Radioactive Waste -- (1) 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, and (2) other highly radioactive materials that the NRC, consistent with existing law, determines by rule requires permanent isolation (10 CFR 60.2, NWSA 2(12)).

In Situ -- In the natural or original position. The phrase is used . . . to distinguish in-place experiments, rock properties, and so on, from those in the laboratory.

In Situ Tests -- Tests that are conducted with subject material in its original place (i.e., at the repository site and depth).

In Situ Test Program -- Consists of a suite of in situ tests conducted within an Exploratory Shaft Facility.

Issue -- A technical question which requires resolution in order that a regulatory performance requirement can be addressed.

Licensing -- The process of obtaining the permits and authorizations from responsible federal, state, and local regulatory agencies required to site, construct, operate, and decommission a repository.

License Application -- An application for permits and authorizations from responsible federal, state, and local regulatory agencies to site, construct, operate, and decommission a repository. Such an application will be accompanied by required

documentation showing that the nuclear facility and its safety-related systems can be operated without undue risk to the health and safety of the public and with adequate provisions for the protection of property and the environment.

Model -- A conceptual description and the associated mathematical representation of a system, subsystem, component, or condition that is used to predict changes from a baseline state as a function of internal and/or external stimuli and as a function of time and space (10 CFR 960.2).

Multibarrier System -- A system of radioactive waste disposal whereby the movement of radionuclides to the biosphere is retarded by the combined action of several independent barriers including the geologic medium, backfill and seals, the waste container, . . . and the waste form itself.

Natural Barrier -- The physical, mechanical, chemical, and hydrological characteristics of the geological environment that, individually and collectively, act to minimize or preclude radionuclide transport.

Natural System -- A candidate host rock for repository construction and waste emplacement, and the surrounding rock formations. It will include natural barriers that provide isolation by limiting radionuclide transport through the geohydrologic environment to the biosphere, and providing conditions that will minimize the potential for human interference in the future.

Performance Criterion -- A criterion establishing quantitative operational, safety, or environmental limits.

Performance Issues -- Broad questions concerning both the operational and long-term performance of the various elements of the overall geologic repository system (e.g., waste form, waste package, geologic setting).

Preclosure -- The period of time before and during the closure of the geologic repository (10 CFR 960.2).

Prewaste-emplacement -- Before the authorization of repository construction by the NRC (10 CFR 960.2).

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.

Radioactive Waste -- In the context of a geologic repository, high level radioactive waste, spent fuel, and other radioactive materials that are received for emplacement in the repository (10 CFR 960.2).

Radioactive Waste Facility -- A facility subject to the licensing and related regulatory authority of the NRC pursuant to Sections 202(3) and 202(4) of the Energy Reorganization Act of 1974 (88 Stat. 1244) (10 CFR 960.2).

Radionuclide -- An unstable, radioactive isotope which decays toward a stable state at a characteristic rate by emitting ionizing radiation(s).

Regulatory Guide -- One of a series of official U.S. Nuclear Regulatory Commission guides prescribing standards and recommendations for nuclear facilities.

Regulatory Requirement -- A performance, information, testing or other requirement specified in one of a series of official Federal regulations governing site selection and investigation, construction, operation, and closure of nuclear waste facilities.

Repository System -- The configuration of man-made features designed to act in harmony with the natural system to provide long-term containment and isolation of nuclear wastes and to provide for receipt, inspection handling, emplacement, and potential retrieval of wastes during the operating phase.

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 (10 CFR 960.2).

Site Investigation -- The program of exploration, both in the laboratory and in the field (e.g., preliminary borings and geophysical testing) conducted during site screening and selection, prior to SCP submittal.

Siting -- The collection of exploration, testing, evaluation, and decision-making activities associated with the process of site screening, site nomination, site recommendation, and site approval for characterization or repository development (10 CFR 960.2).

Underground Facility -- The underground structure and the rock required for support, including openings and backfill materials, but excluding shafts, boreholes, and their seals (10 CFR 960.2).

Waste Emplacement -- The act of emplacing a waste package in a borehole in the underground repository room.*

Waste Package -- The waste form and any containers, shielding, packing, and other sorbent materials immediately surrounding an individual waste container (10 CFR 60.2, 10 CFR 960.2).

*At this time it is not clear whether vertical or horizontal boreholes, or no borehole at all, will be used.

APPENDIX B
STRATIGRAPHY AT THE DEAF SMITH COUNTY SITE

FIGURE B.1 Geologic Log of J. Friemel Well, Deaf Smith County (Source: U.S. Department of Energy, 1986)

TABLE B.1 Estimated Stratigraphy at the Deaf Smith County Site^{a,b}

Geologic Unit	Elevation of Top from Mean Sea Level (ft) ^c	Depth to Top from Ground Surface (ft)	Thickness (ft)	Lithology ^d
Ogallala Formation	4033 ± 2	0	340 ± 25	Reddish-tan claystone and sandstone; unconsolidated to soft; fine subrounded to round grains.
Dockum Group	3693 ± 25	340 ± 25	621 ± 50	Red-brown sandy siltstone with layers of claystone and sandstone; grades into conglomerate.
Dewey Lake Formation	3072 ± 75	961 ± 75	74 ± 20	Red-brown siltstone and claystone.
Alibates Formation	2998 ± 150	1035 ± 150	32 ± 5	Light-green to white dolomite with siltstone.
Salado-Tansill Formation	2966 ± 150	1067 ± 150	67 ± 5	Red-brown siltstone with some gypsum and anhydrite.
Yates Formation	2899 ± 150	1134 ± 150	65 ± 5	Red-brown siltstone and very fine sandstone.
Upper Seven Rivers Formation	2834 ± 150	1199 ± 150	130 ± 15	Interbedded gray anhydrite and red-brown claystone/siltstone; salt with some siltstone/claystone and anhydrite.
Lower Seven Rivers Formation	2704 ± 150	1329 ± 150	194 ± 5	Red-brown siltstone with minor anhydrite.
Queen-Grayburg Formation	2510 ± 150	1523 ± 150	180 ± 10	Red-brown siltstone and sandstone.

TABLE B.1 (Cont'd)

Geologic Unit	Elevation of Top from Mean Sea Level (ft)	Depth to Top from Ground Surface (ft)	Thickness (ft)	Lithology
Upper San Andres Formation	2330 $\pm$ 150	1703 $\pm$ 150	474 $\pm$ 10	Salt with varying amounts of red-brown mudstone impurities and occasional anhydrite and dolomite layers. Mostly anhydrite with interbeds of dolomite and siltstone at the base.
Lower San Andres Unit 5	1856 $\pm$ 150	2177 $\pm$ 150	194 $\pm$ 10	Upper section -- alternating beds of salt with some red-brown mudstone impurities and bluish-gray anhydrite; lower section -- alternating beds of bluish-gray anhydrite and grayish brown dolomite.
Lower San Andres Unit 4	1662 $\pm$ 150	2371 $\pm$ 150	250 $\pm$ 5	Salt with varying amounts of red-brown mudstone. Mainly dolomite and limestone with anhydrite beds at the base.
Lower San Andres Unit 3	1412 $\pm$ 150	2621 $\pm$ 150	120 $\pm$ 5	Clear to white salt with a 30-ft-thick layer of gray-brown anhydritic dolomite and limestone at the base.
Lower San Andres Unit 2	1292 $\pm$ 150	2741 $\pm$ 150	71 $\pm$ 5	Upper section -- salt with red-brown siltstone impurities; lower section -- light- to medium-gray dolomite with occasional interbeds of salt.
Lower San Andres Unit 1	Absent	Absent	Absent	
Glorieta Formation	1221 $\pm$ 150	2812 $\pm$ 150	610 $\pm$ 10	Thick salt sequence with varying quantities of red-brown siltstone impurities; occasional sandstone.

TABLE B.1 (Cont'd)

Geologic Unit	Elevation of Top from Mean Sea Level (ft)	Depth to Top from Ground Surface (ft)	Thickness (ft)	Lithology
Upper Clear Fork Formation	611 ± 150	3422 ± 150	495 ± 10	Mainly salt with some beds of red-brown siltstone, light-tan dolomite and white anhydrite; sequence of white anhydrite, red-brown siltstone, and light-tan dolomite at the base.
Tubb Formation	116 ± 200	3917 ± 200	212 ± 25	Red-brown siltstone and fine sandstone with some anhydrite and salt.
Lower Clear Fork Formation	-96 ± 200	4129 ± 200	294 ± 25	Alternating beds of red-brown siltstone, clear to white salt, and white anhydrite.
Red Cave Formation	-390 ± 200	4423 ± 200	543 ± 20	Red shale with some siltstone and anhydrite.
Wichita Group	-933 ± 250	4966 ± 250	330 ± 20	Upper section -- interbedded anhydrite and red shale with some medium olive-gray dolomite; lower section -- olive gray argillaceous dolomite with anhydrite.
Wolfcamp Series	-1263 ± 250	5296 ± 250	1245 ± 50	Upper section -- thick sequence of olive-gray dolomite (210 ft); middle section -- limestone varying in color from olive gray-tan to dark gray (310 ft); lower section -- dark gray to black argillite (725 ft).
Pennsylvanian System, Upper Section	-2508 ± 350	6541 ± 350	309 ± 50	Alternating shale and tan limestone; grades downward into a thick sequence of medium-gray shale.

TABLE B.1 (Cont'd)

Geologic Unit	Elevation of Top from Mean Sea Level (ft)	Depth to Top from Ground Surface (ft)	Thickness (ft)	Lithology
Pennsylvanian System, Carbonate Section	-2817 ± 400	6850 ± 400	550 ± 75	Limestone and black shale.
Pennsylvanian System, Granite Wash Section	-3367 ± 450	7400 ± 450	683 ± 100	Arkose with thin interbeds of shale and limestone.
Precambrian Basement	-4050 ± 500	8083 ± 500	--	Rhyolite.

^aThe location is assumed to be N 411, 161, E 1,710,436 (Texas coordinate system, north zone), which is the location of a proposed engineering design borehole.

^bAll tabulated thicknesses, depths, and elevations are estimates. Actual values are unknown. It would constitute a misuse of this information to proceed with the expectation that conditions at this site location are exactly as estimated; however, it is likely that actual conditions are within the ranges given.

^cGround-surface elevation at the site location specified in footnote "a" is 4033 ± 2 ft above mean sea level (U.S. Geological Survey, 1966).

^dLithologic descriptions are based on Stone and Webster Engineering Corp., 1984, Table 1 and App. E, and Flawn, 1956.

Source: U.S. Department of Energy, 1986.

References for Appendix B

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APPENDIX C

SUMMARY OF NRC/DOE MEETING ON THE STRUCTURE AND TECTONICS OF THE PALO DURO BASIN

APPENDIX C

SUMMARY OF NRC/DOE MEETING ON THE STRUCTURE AND TECTONICS OF THE PALO DURO BASIN*

DATE/LOCATION

November 18-21, 1985; Park University Hotel, Columbus, Ohio.

OBSERVATIONS

The U.S. Nuclear Regulatory Commission had the following observations:

1. A significant amount of data available for structural interpretations of the Palo Duro Basin consists of boring logs of oil exploration wells and seismic surveys conducted for oil exploration. As part of site screening activities of the entire basin, project-specific seismic data were obtained using acquisition parameters that emphasize resolution in the approximately 2000-6000-ft depth range. As such, the inherent uncertainty and limitations of these data for detailed structural analysis are recognized, particularly with respect to near-surface strata.
2. The nature and distribution of the seismic and boring data are such that some variations in interpretations are possible for both the data and the resultant structural features.
3. Some available seismic data and remote-sensing imagery, such as landsat and aerial photographs, do not appear to have been fully used. Much of the seismic data is proprietary in nature; when approached by DOE contractors, the oil companies have refused to release the data. Other seismic data are known by DOE to be available from brokers; however, the quality and usefulness of these data are not well known. DOE should consider evaluating the availability and usefulness of all seismic data to determine if they can be obtained and if they are worth obtaining to assist in structural interpretations. It should be recognized that NRC has defined procedures for dealing with proprietary data. DOE may also wish to consider obtaining and evaluating other available remote-sensing data, such as various types and scales of aerial photography and radar imagery.

*Excerpted from summary notes provided by NRC/DOE following the meeting on November 18-21, 1985.

4. In the development of its SCPs, DOE should consider developing a comprehensive integration of the available data. The following data elements have been addressed to some degree; however, NRC considers the integration effort should include:
 - a. Development of a conceptual regional tectonic model(s) to evaluate various structural interpretations.
 - b. Evaluations of the possible effects of strike-slip faulting, including both the ability to recognize such features and their effect on structural interpretations.
 - c. Evaluations of the role of the Matador arch and Oldham nose in the regional tectonic setting.
 - d. Evaluations of the relationship between fracture patterns observed in boreholes, outcrops, and remote-sensing data, including the limitations of the various methods in recognizing these features.
 - e. Modeling of gravity and magnetic data.
 - f. Evaluations of potential reactivation of structural features through geologic time, including the upward change in structural expression, such as progression from faulting to folding to fracturing, which may be expected, and variations in fracture density and orientations over areas of deep faults in comparison with unfaulted areas.
 - g. Providing more emphasis on evaluating the presence or absence of folds and their role in the tectonic history of the area.
 - h. Resolving difficulties in identifying basement.
 - i. Reevaluation of the boundaries and the resultant effect of the regional stress field between the approximately N 70° E maximum horizontal stress field of the mid-continent to the approximately N-S stress field of the Rio Grande rift.
5. It appears that DOE's contractors have made significant progress in developing and implementing a viable QA (quality assurance) program; however, NRC questions if traceability of information from study to study can yet be demonstrated. From the meeting presentations, it is NRC's impression that each study is providing some checks and documentation; however, there appears to be little to no effort to cross-check from one study to another. Examples that arose during the meeting include: criteria used to

identify faults on seismic lines, criteria used to eliminate or modify faults presented in the published literature, and subcontractor reports and criteria to select stratigraphic "picks" from borehole logs. DOE may wish to have its QA personnel consider this concern.

6. When planning for seismic reflection surveys, NRC believes that:
 - a. Expanded coverage with seismic refraction profiling may provide much useful information concerning lateral and vertical variations of velocity values. Such information could be useful for (1) drill hole location optimization, (2) geohydrology characterization, (3) planning of seismic reflection lines and evaluation of shallow reflection anomalies.
 - b. Dual programs may be desirable in certain areas to provide both shallow and deep structural data.
 - c. Shallow (less than 2000 ft) surveys should be considered in selected areas where the Alibates Formation is known to be faulted.
7. DOE should consider the usefulness and applicability of electrical and electromagnetic surveys in resolving structural and geohydrologic concerns.
8. On the basis of the DOE presentations of general types of planned site characterization studies, it appears to the NRC that current planning is focusing on developing site-specific studies. It is not as apparent that the same attention has been given to also developing regional investigations important to understanding site performance. During future meetings in which proposed studies are discussed, this subject needs additional clarification. This subject should be evaluated in light of the performance objectives of 10 CFR 60.
9. The NRC staff appreciates the effort of DOE in making available at this meeting the key personnel involved in the structural evaluation of the Palo Duro Basin. The knowledge and candor of the presentors helped assure the success of the meeting in accomplishing its objectives. The NRC staff wishes to thank all DOE participants for their effort.

DOE had the following observations:

1. A common data base has been available to all SRP investigators for use in structural and stratigraphic interpretation; each study

has used selected portions of the data base. The regional nature of the currently available borehole information and seismic surveys permits conflicting structural interpretations.

2. SRP [Salt Repository Project] recognizes a need to develop a uniform approach to evaluation and interpretation of geotechnical data (i.e., criteria for [1] picking formation "tops" from geophysical logs, [2] picking faults on Palo Duro seismic sections, [3] assigning geologic horizons to seismic data, and [4] "time to depth" conversions).
3. It is important to obtain seismic data optimized for both basement structures and shallow structures (repository horizon and above). These two needs lead to conflicting requirements for data acquisition parameters if a single seismic survey is to be used. Consideration should be given to separate surveys for deep and shallow data.
4. The exploration geophysics industry (particularly seismic), is needed by the program because of its expertise, capital equipment, and software. However, the industry's procedures and software are largely proprietary and do not fully comply with the program's general requirements for QA. Nor can the industry be expected to comply by revealing its proprietary programs. Some agreement between NRC and SRP is desirable before site characterization activities to identify the acceptable applications of industry data.
5. The uncertainty in structural maps should be explicitly stated rather than relying solely on the indicated distribution of data points to suggest areas of greater or lesser control.
6. DOE needs to resolve the level of detail needed in structural tectonic models necessary at different phases prior to precicensing studies. Specifically, the interpretation of structures within the tectonic framework and the evaluation of performance objectives must be related to uncertainties inherent in the model.
7. There is the need to clearly define the implications to site performance of tectonism during various geologic periods.
8. Site studies require integration to achieve consistent conceptual models of geology, structure, and hydrology (e.g., structural control of geomorphic processes and depositional patterns, and the interrelationship of the geologic framework to hydrogeologic processes).
9. Available remote-sensing data have not been used and completely evaluated.

10. This meeting demonstrates the desirability of early technical interchanges between DOE and NRC to discuss existing data and uncertainties in interpretations. Such discussions are valuable in expediting the later review of the SCP.
11. It was noted that relatively little information exists concerning the Dockum Formation across the entire Texas Panhandle. Some approaches to enhancing our understanding of this unit include geological and structural mapping in areas of exposure (e.g., Canadian River Valley) and shallow reflection/refraction seismic surveys.
12. With the exception of fracture identification logs, joint information is currently restricted to the periphery of the Southern High Plains. Considerable discussion centered on the implication and meaning of fracture identification logs relative to regional structural interpretations. The nature of the data sets does not permit unambiguous conclusions.

APPENDIX D

SURVEY OF GEOPHYSICAL TECHNIQUES FOR SITE CHARACTERIZATION IN BASALT, SALT, AND TUFF

TABLE D.1 Applicable Geophysical Techniques for Site Characterization in Basalt

Geophysical Method	Faulted Structure		Nonfaulted Structure		Stratigraphic Correlation	Fracturing/ Permeability	Engineering Properties
	Shallow ^a	Deep ^b	Shallow	Deep			
Seismic reflection	● ^{c,d,e}	○ ^f	● ^d	○	●		○
Seismic refraction	○	○ ^g	○	○			
Vertical seismic profiling	●	○ ^h	●	○ ^h			○ ⁱ
Hydraulic vertical seismic profiling						●	
Cross-borehole seismic	○				○	●	●
Gravity	○	○ ^g	○	○			○
Magnetics	●	○	●	○			
Resistivity	○		○				
Induced polarization	○ ^k		○ ^k			○ ^k	
Self-potential							
Ground-penetrating radar							
Electromagnetic methods	○		○				
Magnetotellurics	○	○	○	○			
Borehole logging Electrical	○		○		●	○	
Radioactive					●	○	● ^l
Acoustic					●	●	●

^aStructure is at or above the depth of the proposed repository horizon.

^bStructure is below the depth of the proposed repository horizon.

^c● = useful.

^dUsing high-resolution techniques.

^eMay require special processing (e.g., dip moveout).

^f○ = somewhat useful.

^gDepends on throw of fault.

^hObservation window becomes smaller at bottom of borehole.

ⁱVelocity information from first breaks.

^jBorehole gravity.

^kApplicable only to depths of tens of meters.

^lDensity log only.

Source: Adapted from Jones, G.M., et al., 1986, Survey of Geophysical Techniques for Site Characterization in Basalt, Salt, and Tuff, preliminary draft prepared by Weston Geophysical Corporation for U.S. Nuclear Regulatory Commission, NRC-02-84-001, Task Order No. 0013-2.

TABLE D.2 Applicable Geophysical Techniques for Site Characterization in Bedded Salt

Geophysical Method	Faulted Structure		Nonfaulted Structure		Stratigraphic Correlation	Fracturing/ Permeability	Engineering Properties
	Shallow ^a	Deep ^b	Shallow	Deep			
Seismic reflection	● ^{c,d,e}	●	● ^d	●	●		○ ^f
Seismic refraction		○ ^g		○			
Vertical seismic profiling	●	○ ^h	●	○ ^h			●
Hydraulic vertical seismic profiling						●	
Cross-borehole seismic						●	●
Gravity		○ ^g		○			
Magnetics		○		○			
Resistivity	○		○				
Induced polarization	○ ⁱ		○ ⁱ			○ ^{i,j}	
Self-potential							
Ground-penetrating radar						○ ^k	
Electromagnetic methods	○		○			○ ⁱ	
Magnetotellurics	○	○	○	○			
Borehole logging Electrical					●	○	
Radioactive					●		● ^l
Acoustic					●	●	●

^aStructure is at or above the depth of the proposed repository horizon.

^bStructure is below the depth of the proposed repository horizon.

^c● = useful.

^dUsing high-resolution techniques.

^eMay require special processing (e.g., dip moveout).

^f○ = somewhat useful.

^gDepends on throw of fault.

^hObservation window becomes smaller at bottom of borehole.

ⁱApplicable only to depths of tens of meters.

^jBorehole induced polarization has potential for fracture detection.

^kBorehole ground-penetrating radar has potential for fracture detection.

^lDensity log only.

Source: Adapted from Jones et al. (1986).

TABLE D.3 Applicable Geophysical Techniques for Site Characterization in Domal Salt

Geophysical Method	Faulted Structure		Nonfaulted Structure		Structure of Salt Rock	Fracturing/Permeability	Engineering Properties
	Shallow ^a	Deep ^b	Shallow	Deep			
Seismic reflection	● ^{c,d,e}	○ ^f	● ^d	○	● ^e		
Seismic refraction	●		●		○		
Vertical seismic profiling	●	○ ^g	●	○	●	●	○
Hydraulic vertical seismic profiling						●	
Cross-borehole seismic						○	
Gravity	●	○ ^h	●	○	●		
Magnetics		○		○			
Resistivity	○		○				
Induced polarization	○ ⁱ		○ ⁱ				○ ^{j,l}
Self-potential							
Ground-penetrating radar	●	○	●	○	○	○ ^k	
Electromagnetic methods	○		○			○ ⁱ	
Magnetotellurics	○	○	○	○			
Borehole logging Electrical						○ ^l	
Radioactive							● ^m
Acoustic						● ^l	●

^aStructure is at or above the depth of the proposed repository horizon.

^bStructure is below the depth of the proposed repository horizon.

● = useful.

^dUsing high-resolution techniques.

^eMay require special processing (e.g., dip moveout).

^f○ = somewhat useful.

^gObservation window becomes smaller at bottom of borehole.

^hDepends on throw of fault.

ⁱApplicable to depths of tens of meters.

^jBorehole induced polarization can detect fractures at repository depth.

^kBorehole ground-penetrating radar can detect fractures at repository depth.

^lSediments above salt stack only.

^mDensity log only.

Source: Adapted from Jones et al. (1986).

TABLE D.4 Applicable Geophysical Techniques for Site Characterization in Tuff

Geophysical Method	Faulted Structure		Nonfaulted Structure		Stratigraphic Correlation	Fracturing/ Permeability	Engineering Properties
	Shallow ^a	Deep ^b	Shallow	Deep			
Seismic reflection							
Seismic refraction	o ^c	• ^d	o	•			
Vertical seismic profiling	o		o				
Hydraulic vertical seismic profiling							
Cross-borehole seismic					o	o	•
Gravity	o	o ^e	o	o			o ^f
Magnetics	o	o	o	o			
Resistivity	o		o				
Induced polarization	o ^g		o ^g			o ^{g,h}	
Self-potential							
Ground-penetrating radar						o	
Electromagnetic methods	o		o			o ^g	
Magnetotellurics	o	o	o	o			
Borehole logging							
Electrical					•	o	• ⁱ
Radioactive					•	o ^j	•
Acoustic					•	• ^{k/o} ^l	

^aStructure is at or above the depth of the proposed repository horizon.

^bStructure is below the depth of the proposed repository horizon.

^co = somewhat useful.

^d• = useful.

^eDepends on throw of fault.

^fBorehole gravity.

^gApplicable only to depths less than tens of meters.

^hBorehole induced polarization has potential for fraction detection at repository depths.

ⁱDensity log only.

^jNeutron log does not work in a dry hole.

^kTeleviwer.

^lOther methods.

Source: Adapted from Jones et al. (1986).