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CHAPTER 6

SUITABILITY OF THE DAVIS CANYON SITE FOR SITE CHARACTERIZATION AND FOR DEVELOPMENT AS A REPOSITORY

The "Nuclear Waste Policy Act of 1982" (NWPA) (42 USC Sections 10101-10226) requires the environmental assessment to include a detailed statement of the basis for nominating a site as suitable for characterization. This detailed statement is to be an evaluation of site suitability under the DOE siting guidelines; the evaluation will be the basis for the comparison of sites reported in Chapter 7. Such an evaluation for the Davis Canyon site is presented in Sections 6.2, 6.3, and 6.4 of this chapter, and is based in part on impacts associated with the reference repository design. Given the considerations and conclusions in Section 5.1 and Table 5-1, the evaluation would not change if based on the Mission Plan repository concept. A brief explanation of the siting guidelines--their format, structure, and implementation--is given in Section 6.1.

6.1 THE DOE SITING GUIDELINES

As directed by Section 112 of the NWPA, the DOE has developed "General Guidelines for Recommendation of Sites for Nuclear Waste Repositories." These guidelines have been published as 10 CFR Part 960 (DOE, 1984) (see Chapter 1 for a more detailed discussion of the guideline development process). They are to be used in the remaining steps of the site-selection process for the first repository: the nomination of at least five sites as suitable for characterization, the recommendation of three sites for characterization, and the recommendation of one site for development as a repository.

6.1.1 Format and Structure of the Guidelines

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

As explained in the supplementary information preceding the guidelines, both the postclosure and the preclosure guidelines are subdivided into System and Technical Guidelines. The postclosure System Guideline defines general requirements for the performance of the repository system after closure. These requirements are based generally on the objectives of protecting public health and safety; they are based specifically on the standards promulgated by the U.S. Environmental Protection Agency (EPA) and released as "Environmental Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes" (40 CFR Part 191) (EPA, 1982a) and the criteria promulgated by the Nuclear Regulatory Commission (NRC) in "Disposal of High-Level Radioactive Wastes in Geologic Repositories; Technical Criteria" (10 CFR Part 60) (NRC, 1983a). The postclosure Technical Guidelines specify requirements for one or more elements of the repository system--the physical properties and physical phenomena at the site.

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

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

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

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

6.1.2 Use of the Siting Guidelines in Evaluating Site Suitability

The evaluations of site suitability provide the basis for making the findings that Appendix III of the guidelines (10 CFR Part 960) requires for disqualifying and qualifying conditions. Using the term "apply" to mean to evaluate a condition and make a finding of compliance, this appendix specifies how the guidelines are to be applied at the principal decision points of the siting process: (1) site identification as potentially acceptable, (2) nomination as suitable for characterization or recommendation for characterization, and (3) recommendation for development as a repository. In particular, this appendix specifies the types of findings that are to result from the applications of the disqualifying conditions and the qualifying conditions. Two levels of findings, one showing an increased level of confidence over the other, are specified for both the disqualifying and the qualifying conditions.

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

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

For a site to be nominated, at least a Level 1 finding must be made for each disqualifying condition, and at least a Level 3 finding must be made for each qualifying condition.

For a site to be recommended for development as a repository, a Level 2 finding must be made and supported for each disqualifying condition, and a Level 4 finding must be made and supported for each qualifying condition.

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

An identification of the favorable conditions and potentially adverse conditions present at the site is necessary for evaluating the ability of the site to meet the individual qualifying conditions; before site characterization, that ability is determined largely by examining the balance between those conditions along with information on the repository system. The identification of the favorable and potentially adverse conditions as "present" or "not present" at the site is based on data currently existing for the site or conservative assumptions when the existing data are inadequate for the identification. ("Conservative" assumptions are assumptions that minimize the possibility that later findings will prove the assumptions to be wrong.) In order for a favorable condition to be claimed as "present," it is necessary for the existing data to clearly support that conclusion. Otherwise, the favorable condition is stated to be "not present." Similarly, a potentially adverse condition is stated to be "present" unless the existing data and the conservative assumptions clearly support a conclusion that the condition is "not present." The DOE intends this approach to the identification of favorable and potentially adverse conditions to be conservative, and no credit is taken in the absence of data.

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

6.1.3 Division of the Guidelines into Categories

The NWPA requires two separate evaluations of the suitability of a site as follows:

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

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

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

The guidelines not requiring site characterization as a prerequisite to application are those that do not contribute to establishing the geologic conditions at a site. The guidelines in this category are predominantly concerned with surface conditions, and most of them are preclosure guidelines. The information required to establish compliance with these

guidelines may be obtained before or during site characterization. Section 6.2 presents the evaluations of the site against the guidelines in this category.

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

6.1.4 Formats for the Presentation of Site Evaluations

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

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

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

6.2 SUITABILITY OF THE DAVIS CANYON SITE FOR DEVELOPMENT AS A REPOSITORY UNDER GUIDELINES NOT REQUIRING SITE CHARACTERIZATION

The Nuclear Waste Policy Act of 1982 (NWPA) specifies in Section 112(b)(1)(E)(ii) that the environmental assessment that accompanies nomination of a site shall include:

> an evaluation by the Secretary as to whether such site is suitable for development as a repository under each such guideline that does not require site characterization as a prerequisite for application of such guideline.

The assessment and subsequent categorization of the individual Technical Guidelines as to whether characterization is required is based on the NWPA and U.S. Nuclear Regulatory Commission (NRC) (10 CFR Part 60) definition of site characterization (Section 6.1). On the basis of this definition, it is possible to specify factors or information requirements that can be addressed without site characterization as defined above. These factors generally fall into one of the following groups: socioeconomics, environment, or meteorology (including precipitation). The corresponding Technical Guidelines that address these general factors are:

- 10 CFR 960.4-2-8-2 Site Ownership and Control
- 10 CFR 960.5-2-1 Population Density and Distribution
- 10 CFR 960.5-2-2 Site Ownership and Control
- 10 CFR 960.5-2-3 Meteorology
- 10 CFR 960.5-2-4 Offsite Installations and Operations
- 10 CFR 960.5-2-5 Environmental Quality
- 10 CFR 960.5-2-6 Socioeconomic Impacts
- 10 CFR 960.5-2-7 Transportation.

Table 6-1. Categorization of Guidelines and Findings Based on Application of the Disqualifying and Qualifying Conditions

Guideline		Level of Finding: Disqualifying Condition	Level of Finding: Qualifying Condition
	Guidelines Not Requiring Site Characterization		
960.4-2-8-2	Site Ownership and Control	--	3
960.5-2-1	Population Density and Distribution	1	3
960.5-2-2	Site Ownership and Control	--	3
960.5-2-3	Meteorology	--	3
960.5-2-4	Offsite Installations and Operations	1	3
960.5-2-5	Environmental Quality	1	3
960.5-2-6	Socioeconomic Impacts	1	3
960.5-2-7	Transportation	--	3
960.5-1	Preclosure System Guideline		
	(a)(1) Preclosure Radiological Safety	--	3
	(a)(2) Environment, Socioeconomics, and Transportation	--	3
	Guidelines Requiring Site Characterization		
960.4-2-1	Geohydrology	1	3
960.4-2-2	Geochemistry	--	3
960.4-2-3	Rock Characteristics	--	3
960.4-2-4	Climatic Changes	--	3
960.4-2-5	Erosion	--	3
960.4-2-6	Dissolution	1	3
960.4-2-7	Tectonics	1	3
960.4-2-8-1	Natural Resources	1	3
960.4-1	Postclosure System Guideline	--	3
960.5-2-8	Surface Characteristics	--	3
960.5-2-9	Rock Characteristics	1	3
960.5-2-10	Hydrology	1	3
960.5-2-11	Tectonics	1	3
960.5-1	Preclosure System Guideline		
	(a)(3) Ease and Cost of Siting, Construction, Operation, and Closure	--	3

The evaluation process is not meant to imply that sufficient information is available at this time to fully evaluate compliance of the site with the intent of these guidelines. The distinction is based solely on the definition of site characterization. Table 6-2 presents a summary of the findings for preclosure and postclosure guidelines not requiring site characterization.

6.2.1 Technical Guidelines

This section addresses those Technical Guidelines which do not require site characterization as a prerequisite for their application. These Technical Guidelines establish conditions that shall be considered in determining compliance with the Qualifying Conditions of the pre- and postclosure System Guidelines detailed in Section 6.2.2 and 6.3.2.

6.2.1.1 Site Ownership and Control (Postclosure), Guideline 10 CFR 960.4-2-8-2

The NRC requires the DOE to obtain ownership and control of land and minerals within the controlled area of the repository or the permanent withdrawal and reservation of such land for its use (10 CFR 60.121). Such rights are required largely to help ensure continued functioning of the repository far into the future without adverse human interference. Additional appropriate controls must be established beyond the controlled area, as necessary, to prevent adverse human actions that could significantly reduce the repository's ability to achieve isolation (10 CFR 60.121).

This guideline includes a qualifying condition, one favorable condition, and one potentially adverse condition for analysis. It does not have a disqualifying condition.

6.2.1.1.1 Statement of Qualifying Condition.

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

Evaluation Process. The evaluation process involves the identification of the land required for the repository site, identification of the present ownership of that land and an analysis as to whether the ownership required of the DOE under the guideline can be obtained. A summary of the evaluation is presented in Table 6-2.

Relevant Data. As described in Section 5.1, the repository site will consist of (1) the geologic repository underground operations area of approximately 781 hectares (1,930 acres), (2) a fenced restricted area of approximately 189 hectares (467 acres) for support buildings and repository surface facilities, and (3) a controlled area extending outward from the edge of the underground facility. Under EPA regulations, this controlled area could extend 5 kilometers (3.1 miles) in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system, potentially encompassing thousands of acres. However, the controlled area need not be this large if the EPA standards for radioactive releases to the accessible environment can be met in a shorter distance (40 CFR Part 191). The size of the controlled area at a given site depends on the rate of ground-water flow and other site characteristics, and can be established on a site-specific basis only after completion of site characterization studies.

NRC Regulation 10 CFR 60.121 (Requirements for Land Ownership and Control of Interests in Land) specifies that both the geologic repository operations area and the controlled areas must be located in and on lands that are either acquired lands under the jurisdiction and control of the DOE, or in and on lands permanently withdrawn and reserved for its use. The repository lands must be held free and clear of all significant encumbrances including mining rights, rights-of-way, easements, and all other rights. The DOE must establish and maintain

Table 6-2. Preclosure and Postclosure Technical Guidelines Not Requiring Site Characterization for the Davis Canyon Site

Statement of Technical Guideline	10 CFR Guideline Number	EA Section Number	Assessment Results	Findings
Site Ownership and Control	960.4-2-8-2	6.2.1.1		
(a) Qualifying Condition				
The site shall be located on land for which the DOE can obtain, in accordance with the requirements of 10 CFR Part 60, ownership, surface and subsurface rights and control of access that are required in order that potential surface and subsurface activities at the site will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.			Through Congressional action, land for the repository and controlled area can be obtained so that surface and subsurface activities will not lead to radionuclide releases greater than those allowable under requirements specified in Section 960.4-1.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
(b) Favorable Condition				
Present ownership and control of land and all surface and subsurface rights by DOE.			Present ownership is not by the DOE.	The evidence indicates that the favorable condition is not present.
(c) Potentially Adverse Condition				
Projected land-ownership conflicts that cannot be successfully resolved through voluntary purchase-sell agreements, nondisputed agency-to-agency transfers of title, or Federal condemnation proceedings.			It is expected that title to both surface and subsurface rights can be obtained. However, Congressional action will be required to permanently withdraw land for DOE. Required interest in land will have been acquired in the preclosure period.	The evidence indicates that the potentially adverse condition is not present.
(d) Disqualifying Condition				
This guideline has no disqualifying condtion.				
Population Density and Distribution	960.5-2-1	6.2.1.2		
(a) Qualifying Condition				
The site shall be located such that, during repository operation and closure, (1) the expected average radiation dose to members of the public within any highly populated area will not be likely to exceed a small fraction of the limits allowable under the requirements specified in Section 960.5-1(a)(1), and (2) the expected radiation dose to any member of the public in an unrestricted area will not be likely to exceed the limits allowable under the requirements specified in Section 960.5-1(a)(1).			The maximum exposed individual is expected to receive an annual dose of less than 2.0 mrem/year from all pathways, below the regulatory limit.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
(b) Favorable Conditions	960.5-2-1	6.2.1.2		
(1) A low population density in the general region of the site.	960.5-2-1	6.2.1.2	Average population density in the site region is 3.8 persons per square mile.	The evidence indicates that the favorable condition is present.
(2) Remoteness of the site from highly populated areas.			There are no highly populated areas in the site vicinity.	The evidence indicates that the favorable condition is present.

Table 6-2. Preclosure and Postclosure Technical Guidelines Not Requiring Site Characterization for the Davis Canyon Site
(Page 2 of 10)

Statement of Technical Guideline	10 CFR Guideline Number	EA Section Number	Assessment Results	Findings
(c) Potentially Adverse Conditions				
(1) High residential, seasonal, or daytime population density within the projected site boundaries.	960.5-2-1	6.2.1.2	The site has no residential and minimal seasonal or daytime population.	The evidence indicates that the potentially adverse condition is not present.
(2) Proximity of the site to highly populated areas, or to areas having at least 1,000 individuals in an area 1 mile by 1 mile as defined by the most recent decennial count of the U.S. Census.	960.5-2-1	6.2.1.2	Moab, the closest highly populated area, is 53 kilometers (33 miles) away.	The evidence indicates that the potentially adverse condition is not present.
(d) Disqualifying Conditions	960.5-2-1	6.2.1.2		
A site shall be disqualified if:				
(1) Any surface facility of a repository would be in a highly populated area; or			The site is 53 kilometers (33 miles) from a highly populated area.	The evidence supports a finding that the site is not disqualified on the basis of that evidence and is not likely to be disqualified (Level 2).
(2) Any surface facility of a repository would be located adjacent to an area 1 mile by 1 mile having a population of not less than 1,000 individuals as enumerated by the most recent U.S. Census; or	960.5-2-1	6.2.1.2	The site is located 53 kilometers (33 miles) from such an area.	The evidence supports a finding that the site is not disqualified on the basis of that evidence and is not likely to be disqualified (Level 2).
(3) The DOE could not develop an emergency preparedness program which meets the requirements specified in DOE Order 5500.3 (Reactor and Non-Reactor Facility Emergency Planning, Preparedness, and Response Program for Department of Energy Operations) and related guides or, when issued by the NRC, in 10 CFR 60, Subpart I, "Emergency Planning Criteria."	960.5-2-1	6.2.1.2	Based on past experience in similar areas (The Nevada Test Site) such a plan can be prepared.	The evidence does not support a finding that the site is disqualified (Level 1).
Site Ownership and Control	960.5-2-2	6.2.1.3		
(a) Qualifying Condition				
The site shall be located on land for which the DOE can obtain, in accordance with the requirements of 10 CFR 60.121, ownership, surface and subsurface rights, and control of access that are required in order that surface and subsurface activities during repository operations and closure will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1).			The Davis Canyon site is located on land for which the Federal government can obtain ownership, control access, and acquire the necessary rights, including water, through negotiations, or, if necessary, condemnation to ensure that any site activities will not lead to a projection of radionuclide releases to an unrestricted area greater than those discussed in Section 960.5-1(a)(1).	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
(b) Favorable Conditions				
Present ownership and control of the land and all surface and subsurface mineral and water rights by the DOE.			The DOE does not currently own and control the land and all surface and subsurface mineral and water rights.	The evidence indicates that the favorable condition is not present.

Table 6-2. Preclosure and Postclosure Technical Guidelines Not Requiring Site Characterization for the Davis Canyon Site
(Page 3 of 10)

Statement of Technical Guideline	10 CFR Guideline Number	EA Section Number	Assessment Results	Findings
(c) Potentially Adverse Condition				
Projected land-ownership conflicts that cannot be successfully resolved through voluntary purchase-sell agreements, non-disputed agency-to-agency transfer of title, or Federal condemnation proceedings.	960.5-2-2	6.2.1.3	Congressional action is required to permanently acquire most of the land required.	The evidence indicates that the potentially adverse condition is present.
Meteorology	960.5-2-3	6.2.1.4		
(a) Qualifying Condition				
The site shall be located such that expected meteorological conditions during repository operations and closure will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1).			Predictions of radioactive emissions from repository operations and closure are below allowable limits.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
(b) Favorable Conditions				
Prevailing meteorological conditions such that any radioactive releases to the atmosphere during respository operation and closure would be effectively dispersed, thereby reducing significantly the likelihood of unacceptable exposures to any member of the public in the vicinity of the repository.			Potential for local weather inversions to trap emissions.	The evidence indicates that the favorable condition is not present.
(c) Potentially Adverse Conditions				
(1) Prevailing meteorological conditions such that radioactive emissions from repository operation and closure could be preferentially transported toward localities in the vicinity of the repository with higher population densities than are the average for the region.			Moab is 53 kilometers (33 miles) downwind from the site.	The evidence indicates that the potentially adverse condition is present.
(2) History of extreme weather phenomena--such as hurricanes, tornadoes, severe floods or severe and frequent winter storms--that could significantly affect repository operation or closure.			Severe weather such as local flooding, heavy fog, and snow occur in the vicinity of the site.	The evidence indicates that the potentially adverse condition is present.
Offsite Installation and Operations	960.5-2-4	6.2.1.5		
(a) Qualifying Condition				
The site shall be located such that present and projected effects from nearby industrial, transportation, and military installatons and operations, including atomic energy defense activities			There are no nearby industrial, transportation, or military installations. Releases from nearly nuclear facilities, when combined with potential releases from the repository, will not result in radiation releases greater than allowable limits.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

Table 6-2. Preclosure and Postclosure Technical Guidelines Not Requiring Site Characterization for the Davis Canyon Site
(Page 4 of 10)

Statement of Technical Guideline	10 CFR Guideline Number	EA Section Number	Assessment Results	Findings
(1) Will not significantly affect repository siting, construction, operation, closure, or decommissioning, or can be accommodated by engineering measures, and (2) When considered together with emissions from repository operation and closure, will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1).	960.5-2-4	6.2.1.5		
(b) Favorable Condition				
Absence of contributing radioactive releases from other nuclear installations and operations that must be considered under the requirements of 40 CFR 191, Subpart A.			There are three uranium mills within 81 kilometers (50 miles) of the site that contribute radioactive releases which must be considered.	The evidence indicates that the favorable condition is not present.
(c) Potentially Adverse Conditions				
(1) The presence of nearby potentially hazardous installations or operations that could adversely affect repository operation or closure.			There are currently no potentially hazardous installations or operation in the site vicinity.	The evidence indicates that the potentially adverse condition is not present.
(2) Presence of other nuclear installations and operations, subject to the requirements of 40 CFR Part 190 or 40 CFR Part 191, Subpart A, with actual or projected releases near the maximum value permissible under those standards.			Radioactive releases from 3 uranium mills within 81 kilometers (50 miles) of the site are not expected to be near the maximum permissible levels.	The evidence indicates that the potentially adverse condition is not present.
(d) Disqualifying Condition				
A site shall be disqualified if atomic energy defense activities in proximity to the site are expected to conflict irreconcilably with respository siting, construction, operation, closure, or decommissioning.			There are no atomic energy defense facilities in proximity to the site.	The evidence does not support a finding that the site is disqualified (Level 1).
Environmental Quality	960.5-2-5	6.2.1.6		
(a) Qualifying Condition				
The site shall be located such that				
(1) The quality of the environment in the affected area during this and future generations will be adequately protected during repository siting, construction, operation, closure, and decommissioning, and projected environmental impacts can be mitigated to an acceptable degree, taking into account programmatic, technical, social, economic, and environmental factors;			Impacts can be acceptably mitigated to prevent significant adverse environmental consequences.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

Table 6-2. Preclosure and Postclosure Technical Guidelines Not Requiring Site Characterization for the Davis Canyon Site
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Statement of Technical Guideline	10 CFR Guideline Number	EA Section Number	Assessment Results	Findings
(2) The requirements specified in Section 960.5-1(a)(2) can be met.	960.5-2-5	6.2.1.6	No identifiable adverse impact significant enough to prevent System Guideline 960.5-1 (a)(2) from being met.	
(b) Favorable Conditions				
(1) Projected ability to meet, within time constraints, all Federal, State, and local procedural and substantive environmental requirements applicable to the site and the activities proposed to take place thereon.			Ability to meet environmental requirements in time is uncertain.	The evidence indicates that the favorable condition is not present.
(2) Potential significant adverse environmental impacts to present and future generations can be mitigated to an insignificant level through the application of reasonable measures, taking into account technical, social, economic, and environmental factors.			The DOE can not project that all potential significant adverse environmental impacts can be mitigated to an insignificant level.	The evidence indicates that the favorable condition is not present.
(c) Potentially Adverse Conditions				
(1) Projected major conflict with applicable Federal, State, or local environmental requirements.	960.5-2-5	6.2.1.6	Major conflicts with any Federal or federally-mandated, State or local environmental requirements are not projected.	The evidence indicates that the potentially adverse condition is not present.
(2) Projected significant adverse environmental impacts that cannot be avoided or mitigated.			All projected significant adverse impacts can be mitigated with the exception of the degradation of air quality within Canyonlands National Park during repository operation.	The evidence indicates that the potentially adverse condition is present.
(3) Proximity to, or projected significant adverse environmental impacts of the repository or its support facilities on, a component of the National Park System, the National Wildlife Refuge System, the National Wild and Scenic Rivers System, the National Wilderness Preservation System, or National Forest Land.			The site is proximal to the Canyonlands National Park. Repository operation will cause degradation of air quality within the park. The repository activities will be visible and audible from several places within the park.	The evidence indicates that the potentially adverse condition is present.
(4) Proximity to, and projected significant adverse environmental impacts of the repository or its support facilities on, a significant State or regional protected resource area, such as a State park, a wildlife area, or a historical area.			Potential for significant adverse impacts may occur at Newspaper Rock near the site.	The evidence indicates that the potentially adverse condition is present.
(5) Proximity to, and projected significant adverse environmental impacts of the repository and its support facilities on, a significant Native American Resource, such as a major Indian religious site, or other site, or other sites of unique cultural interest.			No significant adverse impacts are expected at the nearest significant Native American resource (Salt Creek Archaeological District).	The evidence indicates that the potentially adverse condition is not present.

Table 6-2. Preclosure and Postclosure Technical Guidelines Not Requiring Site Characterization for the Davis Canyon Site
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Statement of Technical Guideline	10 CFR Guideline Number	EA Section Number	Assessment Results	Findings
(6) Presence of critical habitats for threatened or endangered species that may be compromised by the repository or its support facilities.	960.5-2-5	6.2.1.6	No Critical habitat for threatened or endangered species has been identified on or near the site to date.	The evidence indicates that the potentially adverse condition is not present.
(d) Disqualifying Conditions. Any of the following shall disqualify the site:				
(1) During repository siting, construction, operation, closure, or decommissioning the quality of the environment in the affected area could not be adequately protected or projected environmental impacts in the affected area could not be mitigated to an acceptable degree taking into account programmatic, technical, social, economic, and environmental factors.			Air Quality - Although preliminary air quality modeling indicates that air quality will be degraded, air quality impacts will be mitigated to an acceptable degree. Water Quality - Surface and ground-water contamination by process wastewater or surface runoff can be mitigated through the use of reasonable engineering practices. Possible leaching of salt into ground water will result in negligible impacts. Cultural Resources - There are no cultural resources in the immediate vicinity of the proposed site, which are eligible for listing on the National Register. Newspaper Rock State Historical Monument will experience temporary (7 years) and reversible effects from increased noise and traffic. Biota - No critical habitat for the threatened or endangered species have been identified in the immediate vicinity of the site. Land Use - The most important consideration in terms of land use is the proximity of the site to the Needles District of the Canyonlands National Park. This site does not appear to have any irreconcilable conflicts with designated land uses. Noise - Opportunities for solitude in Canyonlands National Park proposed Wilderness Area and in the Bridger Jack Area Wilderness Study Area will be diminished from elevated noise levels but will be much less than from periodic commercial airline overflights in the area. Salt Management and Disposal. For the projected volumes of salt to be disposed of, rate and length of time of discharge, practical mitigative measures can be implemented so that there would be no significant adverse environmental impact. Radiological - A conservative predictive radiological impact analysis indicates that exposures of the public during construction and operation of the repository will be below health and safety requirements established by the NRC and the EPA.	The evidence does not support a finding that the site is disqualified (Level 1).

Table 6-2. Preclosure and Postclosure Technical Guidelines Not Requiring Site Characterization for the Davis Canyon Site
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Statement of Technical Guideline	10 CFR Guideline Number	EA Section Number	Assessment Results	Findings
			Soils - The amount of land withdrawn for repository development is less than 1 percent of the total for San Juan County. This is not likely to have an unacceptable adverse impact on the quality of the environment.	
	960.5-2-5	6.2.1.6	Visual Aesthetics. Although the facility would have a high degree of visibility, no unique features are likely to be significantly affected by the construction, operation, or closure of the repository.	
(2) Any part of the restricted area or repository support facilities would be located within the boundaries of a component of the National Park System, the National Wildlife System, the National Wilderness Preservation System, or the National Wild and Scenic Rivers System.			No part of the repository or support facilities or restricted area will be within such designated areas.	The evidence does not support the finding that the site is disqualified (Level 1).
(3) The presence of the restricted area or the repository support facilities would conflict irreconcilably with the previously designated use of a component of the National Park System, the National Wildlife Refuge System, the National Wildlife Wilderness Preservation System, the National Wild and Scenic Rivers System, or National Forest Lands, or any comparably significant State protected resource that was dedicated to resource preservation at the time of the enactment of the Act.			The presence of the repository support facilities or restricted area is not expected to cause irreconcilable conflicts.	The evidence does not suport the finding that the site is disqualified (Level 1).
Socioeconomic Impacts	960.5-2-6	6.2.1.7		
(a) Qualifying Conditions				
The site shall be located such that				
(1) Any significant adverse social and/or economic impacts induced in communities and surrounding regions by respository siting, construction, operation, closure, and decommissioning can be offset by reasonable mitigation or compensation as determined by a process of analysis, planning, and consultation among the DOE, affected State and local government jurisdictions, and affected Indian tribes; and (2) the requirements specified in Section 960.5-1(a)(2) can be met.			Based on the analysis of existing information, reasonable mitigation or compensation can offset adverse impacts and requirements can be met.	The evidence does not suport a finding that the site is not likely to meet the qualifying condition (Level 3).
(b) Favorable Conditions				
(1) Ability of an affected area to absorb the project-related population changes without significant disruptions of community services and without significant impacts on housing supply and demand.			The projected net change in total population in the study area is greater than 20% of the existing population during the peak period. Community infrastructure will need to be developed or the impacts on local housing schools, etc. will be severe.	The evidence indicates that the favorable condition is not present.
(2) Availability of an adequate labor force in the affected area.			Less than 20 percent of the peak labor force demand can be met with the existing local work force.	The evidence indicates that the favorable condition is not present.

Table 6-2. Preclosure and Postclosure Technical Guidelines Not Requiring Site Characterization for the Davis Canyon Site
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Statement of Technical Guideline	10 CFR Guideline Number	EA Section Number	Assessment Results	Findings
(3) Projected net increases in employment and business sales, improved community services, and increased government revenues in the affected area.			Jobs created by repository construction and operation and direct material purchases will increase employment and business sales.	The evidence indicates that the favorable condition is present.
(4) No projected substantial disruption of primary sectors of the economy of the affected area.			Retail and service sectors should have a net increase in sales. Due to the increased population, loss in tourism will be offset by the overall economic growth.	The evidence indicates that the favorable condition is present.
(c) Potentially Adverse Conditions				
(1) Potential for significant repository-related impacts on community services, housing supply and demand, and the finances of State and local goverment agencies in the affected area.			The impact on community services and housing supply will be significant because of cumulative growth impacts on area communities.	The evidence indicates that the potentially adverse condition is present.
(2) Lack of an adequate labor force in the affected area.			There is a small local labor force.	The evidence indicates that the potentially adverse condition is present.
(3) Need for repository-related purchase or acquisition of water rights, if such rights could have significant adverse impacts on the present or future development of the affected area.			Alternative water sources are available and would not affect present or future development.	The evidence indicates that the potentially adverse condition is not present.
(4) Potential for major diaruptions of primary sectors of the economy of the affected area.			Retail and service sectors should have a net increase in sales.	The evidence indicates that the potentially adverse condition is not present.
(d) Disqualifying Condition				
A site shall be disqualified if repository construction, operation, or closure would significantly degrade the quantity of water from major sources of offsite suppliers presently suitable for human consumption or crop irrigation and such impacts cannot be compensated for, or mitigated by, reasonable measures.			Any potential degradation of surface- and ground-water quality and quantity can be mitigated by planned engineering and design measures.	The evidence does not support a finding that the site is disqualified (Level 1).
Transportation	960.5-2-7	6.2.1.8		
(a) Qualifying Condition				
The site shall be located such that (1) the access routes constructed from existing local highways and railroads to the site (i) will not conflict irreconcilably with the previously designated use of any resources listed in 960.5-2-5(d)(2) and (3); (ii) can be designed and constructed using reasonably available technology; (iii) will not require transportation system components to meet performance standards more stringent than those specified in the applicable DOT and NRC regulations,			Based on preliminary analysis of representative access routes and projected transportation operations there is no indication that the qualifying condition cannot be met.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

Table 6-2. Preclosure and Postclosure Technical Guidelines Not Requiring Site Characterization for the Davis Canyon Site
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Statement of Technical Guideline	10 CFR Guideline Number	EA Section Number	Assessment Results	Findings
or require the development of new packaging containment technology; (iv) will allow transportation operations to be conducted without causing an unacceptable risk to the public or unacceptable environmental impacts; and taking into account programmatic, technical, social, economic, and environmental factors; and (2) the requirements of Section 960.5-1 (a)(2) can be met.	960.5-2-7	6.2.1.8		
(b) Favorable Conditions				
(1) Availability of access routes from local existing highways and railroads to the site which have any of the following characteristics:			None of the cited characteristics are present (ii and v).	The evidence indicates that the favorable condition is not present.
(i) Such routes are relatively short and economical to construct as compared to access routes for other comparable siting options.				
(ii) Federal condemnation is not required to acquire rights-of-way for the access routes.				
(iii) Cuts, fills, tunnels, or bridges are not required.				
(iv) Such routes are free of sharp curves or steep grades and are not likely to be affected by landslides or rock slides.				
(v) Such routes bypass local cities and towns.				
(2) Proximity to local highways and railroads that provide access to regional highways and railroads and are adequate to serve the repository without significant upgrading or reconstruction.			Significant upgrading of portions of U.S. 191 and U.S. 666 is anticipated at a cost of approximately $35 million.	The evidence indicates that the favorable condition is not present.
(3) Proximity to regional highways, mainline railroads, or inland waterways that provide access to the national transportation system.			The distance to I-70 from the end of the access route alternatives ranges from 103 to 155 kilometers (64 to 96 miles) from 48 to 58 kilometers (30 to 36 miles).	The evidence indicates that the favorable condition is not present.
(4) Availability of a regional railroad system with a minimum number of interchange points at which train crew and equipment changes would be required.			There are 3 interchanges per routing.	The evidence indicates that the favorable condition is not present.
(5) Total projected life-cycle cost and risk for transportation of all wastes designated for the repository site which are significantly lower than those for comparable siting options, considering locations of present and potential sources of wastes, interim storage facilities, and other repositories.			Analysis of existing data shows the cost and risks to be higher than for other sites (see Chapter 7 for comparison).	The evidence indicates that the favorable condition is not present.

Table 6-2. Preclosure and Postclosure Technical Guidelines Not Requiring Site Characterization for the Davis Canyon Site
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Statement of Technical Guideline	10 CFR Guideline Number	EA Section Number	Assessment Results	Findings
(6) Availability of regional and local carriers--trucks, rail, and water--which have the capability and are willing to handle waste shipments to the repository.	960.5-2-7	6.2.1.8	One railroad and eight motor carriers are available to handle waste shipments to the repository.	The evidence indicates that the favorable condition is present.
(7) Absence of legal impediment with regard to compliance with Federal regulations for the transportation of waste in or through the affected State and adjoining States.			State and Local ordinances are not expected to impede transportation.	The evidence indicates that the favorable condition is present.
(8) Plans, procedures, and capabilities for response to radioactive waste transportation accidents in the affected State that are completed or being developed.			The State Emergency Operations Plans covers hazardous and nuclear materials incidents.	The evidence indicates that the favorable condition is present.
(9) A regional meteorological history indicating that significant transportation disruptions would not be routine seasonal occurrences.			Temporary seasonal disruptions may occur because of seasonal storms, but these will not result in significant disruptions.	The evidence indicates that the favorable condition is present.
(c) Potentially Adverse Conditions				
(1) Access routes to existing local highways and railroads that are expensive to construct relative to comparable siting options.			Access route construction in the Paradox Basin is expected to cost as much as $79 million for highway and $269 million for rail access.	The evidence indicates that the potentially adverse condition is present.
(2) Terrain between the site and existing local highways and railroads such that steep grades, sharp switchbacks, rivers, lakes, landslides, rock slides, or potential sources of hazard to incoming waste shipments will be encountered along access routes to the site.			The terrain between existing local highways and railroads has steep grades and landslide potential. A crossing of the Colorado River is necessary for rail access.	The evidence indicates that the potentially adverse condition is present.
(3) Existing local highways and railroads that could require significant reconstruction or upgrading to provide adequate routes to the regional and national transportation system.			Substantial portions of highways will require improvement.	The evidence indicates that the potentially adverse condition is present.
(4) Any local condition that could cause the transportation-related costs, environmental impacts, or risk to public health and safety from waste transportation operations to be significantly greater than those projected for other comparable siting options.			Transportation related impacts are significantly greater than for other sites (see Chapter 7 for comparison).	The evidence indicates that the potentially adverse condition is present.
(d) Disqualifying Condition				
This guideline has no disqualifying condition.				

appropriate jurisdiction and controls of the controlled-area lands that are necessary to prevent adverse human actions that could significantly reduce the geologic repository's capability to isolate waste. A conservative estimate based on preliminary data related to radionuclide release time is that 2,331 hectares (5,760 acres) would allow all EPA and NRC radionuclide release requirements to be met (see Sections 6.3 and 6.4).

Present Ownership of the Land. Land within the site comprises approximately 92 percent federally owned lands managed by the Bureau of Land Management (BLM), 4 percent State-owned lands, and 4 percent private lands (Section 3.4.1.1 and Section 4.1.2.1).

Assumptions and Data Uncertainty. The number of acres that will comprise the controlled area is a preliminary estimate based on available data. The final determination of the actual size of the controlled area at the site will depend on the rate of ground-water flow, as well as other site characteristics, and will be established after completion of site characterization studies to ensure that releases to the accessible environment will not exceed those permitted by the U.S. Environmental Protection Agency (EPA) (40 CFR Part 191 [EPA, 1982b]).

As a separate consideration, the DOE does not anticipate that any additional control outside the controlled area will be required to prevent adverse human actions (10 CFR 60.121[b]). The DOE controlled-area estimate is conservative and already includes a buffer area, beyond that otherwise required on performance assessment grounds, to account for potential human intrusion (Chen and Raines, 1985).

Analysis. Because most of the site is located on public land managed by the BLM, Congressional action is required to permanently withdraw the land. On State-owned and privately owned land, fee simple ownership of the surface and subsurface will afford the DOE maximum control over the repository site. If negotiations are unsuccessful, the DOE has authority under Federal law to condemn.

6.2.1.1.2 Analysis of Favorable Condition.

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

Evaluation. The DOE does not presently own or control the land and all surface and subsurface rights. The DOE will have to acquire the necessary rights as discussed above.

The evidence indicates that the favorable condition is not present.

6.2.1.1.3 Analysis of Potentially Adverse Condition.

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

Evaluation. The Davis Canyon site is located primarily on public land managed by the BLM. To acquire this land, a Congressional action is required to withdraw the land permanently. The balance is located on State and private land. The DOE will acquire this property by voluntary purchase or Federal condemnation, if necessary. Required interest in land will have been acquired by the DOE in the preclosure time period if the site is selected for a repository, and there will be no postclosure land-ownership conflicts.

The evidence indicates that the potentially adverse condition is not present.

6.2.1.1.4 Analysis of Disqualifying Condition. The site ownership and control guideline does not have a disqualifying condition.

6.2.1.1.5 Conclusion for the Qualifying Condition. The favorable condition is not present in that the DOE does not presently have ownership of the land and all surface and subsurface rights, nor has it been permanently withdrawn and reserved for its use.

The potentially adverse condition is present. However, the Davis Canyon site is located on land for which the DOE can obtain ownership and control access to ensure that any site activities will not lead to a projection of radionuclide releases to an unrestricted area greater than those discussed in Section 960.4-1 through permanent withdrawal on public land and through negotiation and, if necessary, condemnation on State-owned or private land. The DOE will acquire all necessary land prior to repository construction. No additional land requirements are antici-pated for the postclosure period.

The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.2.1.2 Population Density and Distribution, Guideline 10 CFR 960.5-2-1

The objective of the population density and distribution guideline is to ensure the selection of a repository site that will minimize risk to the public and permit compliance with the EPA and NRC regulations. The EPA standard (40 CFR Part 191) limits exposures to members of the public and further requires that these exposures be reduced below the limits to the extent reasonably achievable. The proposed EPA standard limits the radiation dose that any individual outside the boundary of the restricted area would receive to a maximum yearly dose of 25 millirem to the whole body, 75 millirem to the thyroid, or 25 millirem to any other organ. (Doses from natural background radiation vary between 70 and 200 millirem per year at different locations in the United States.) The doses that would result from repository releases are very much lower than the EPA maximum permissible doses.

This guideline includes a qualifying condition, two favorable conditions, and two potentially adverse conditions for analysis. It also has three disqualifying conditions.

6.2.1.2.1 Statement of Qualifying Condition.

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

Evaluation Process. A conservative approach was taken for assessing compliance with this guideline by showing that an individual at the site boundary, exposed continuously to normal operational and accidental releases of radioactivity, will not receive a dose that exceeds a small fraction of the limits. Both operation and closure of the facility are considered. This requires knowledge of the characteristics of the release rate of each radionuclide and the release height, as well as atmospheric transport-related parameters, receptor location and number, dose equivalent properties of the radionuclides released, a dose assessment, and a comparison to the EPA dose limits (40 CFR Part 191).

The guideline requires consideration of (1) the population density in the general region of the site; (2) the remoteness of the site from highly populated areas; (3) the residential, seasonal, or daytime population density within the projected site boundary; (4) proximity of the site to highly populated areas, or to areas having at least 1,000 individuals in a 1.6 kilometer by 1.6 kilometer (1 mile by 1 mile) area; and (5) the ability to develop an emergency preparedness plan. A summary of the evaluation is presented in Table 6-2.

Relevant Data. The data relevant to making this assessment are presented in Section 6.4.1. Characteristics of the release rate of each radionuclide and the release height, atmospheric transport-related parameters, dosimetric properties of the radionuclides released, and dose assessment results are presented and discussed in Section 6.4.1. The primary sources of data for this analysis are found in Sections 3.4.1, Land Use; 3.4.3,

Meteorology; 3.6.1, Population Density and Distribution; 5.1, The Repository; and 6.4.1, Preclosure Radiological Assessment for Davis Canyon.

Assumptions and Data Uncertainty. Demographic data for the Paradox Region were collected during the 1980 Census and compiled in the socioeconomic data base report (BGI, 1984, ONWI-471). Meteorological data at the site are not available. Anticipating that the micrometeorological characteristics of the site will be important and that the regional nature of the Paradox Basin Environmental Characterization Report (BGI, 1982, ONWI-144) does not adequately reflect these characteristics, very poor atmospheric dispersion was assumed for normal releases.

The facility design has to be considered preliminary and subject to continuing change as further knowledge is gained. This design is believed to be reasonably representative of the repository operational systems likely to be included in future designs. For this evaluation the site boundary is considered to be at the edge of the restricted area.

Analysis. Two types of conservative analyses are used to show compliance with the requirements of the Technical Guideline. In the first analysis, releases of radionuclides at the point of release are compared to 10 CFR Part 20 (NRC, 1983b) requirements for maximum permissible concentrations in unrestricted areas. In the second, calculation is made of the annual dose to a hypothetical individual who is presumed to be continuously at the point of maximum exposure in the unrestricted area. This exposure is compared to regulatory limits. Radiological analyses are detailed in Section 6.4.1.

Section 6.4.1 shows that repository construction will result in radionuclide-release concentrations of less than 0.04 percent of 10 CFR Part 60 limits for releases to the unrestricted environment. Repository operational releases are expected to be less than 1 percent of the same limit. Atmospheric dispersion can be expected to further reduce concentrations before released radionuclides are transported to the unrestricted environment.

Section 6.4.1 shows that a maximum exposed individual is predicted to receive an annual dose of 1.3 millirem per year from all pathways (inhalation, submersion, and ingestion). This exposure is well below the regulatory limit of 25 millirem per year.

Potential releases of radioactivity following repository closure were not evaluated; however, these emissions should be much lower than during operation, because waste receipt and waste handling have ceased.

6.2.1.2.2 Analysis of Favorable Conditions

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

Evaluation. The average population density in the 80-kilometer (50-mile) radius around the site is 3.8 persons per square mile. This is substantially lower than the national average of 76 persons per square mile for the continental United States.

The evidence indicates that the favorable condition is present.

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

Evaluation. Any evaluation of this favorable condition requires a precise definition of remoteness which is not provided in the guidelines. Therefore, for the purpose of this evaluation, remoteness has been equated to a distance of 8 kilometers (5 miles) beyond the anticipated control zone.

The 8-kilometer (5-mile) criterion is based on analogy with two nuclear power reactor precedents. First, for U.S. nuclear power plants, the Low Population Zones (LPZ) vary from 0.97 to 9.7 kilometers (0.6 to 6 miles) as calculated on the basis of "Reactor Site Criteria" 10 CFR 100.11 (Pearlman and Waite, 1984, p. 40). Also, evacuation zones in Federal Emergency

Management Agency (FEMA) regulations are defined by radii of 3.2 and 8 kilometers (2 and 5 miles) (Pearlman and Waite, 1984, p. 41).

The preclosure emissions from the repository will originate within the restricted area. A conservative approach of originating the 8 kilometer (5-mile) measurement on the boundary of the controlled area was adopted.

There are no highly populated areas (2,500 or more persons [10 CFR Part 960]) in the immediate vicinity of the site. The closest highly populated areas are Moab, which has 5,333 persons and is approximately 53 kilometers (33 miles) in air distance away, and Blanding, which has 3,118 persons and is approximately 56 kilometers (35 miles) in air distance from the boundary of the controlled area.

The evidence indicates that the favorable condition is present.

6.2.1.2.3 Analysis of Potentially Adverse Conditions.

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

Evaluation. The site is remote. There is no residential population within the projected site boundaries. Daytime population would be limited to off-road vehicle users passing by the site on the way to the portion of Davis Canyon located in the park. Davidson-Peterson Associates and PBQ&D (1978) indicate that about 1 percent of the Canyonlands National Park visitors use this vehicle corridor. This would have been equal to about 1,000 persons in 1983. Based on this, it is estimated that during the peak month of park visitation less than seven persons a day would cross the site. The population density represented by this number of persons is far less than the average U.S. density of 76 persons per square mile.

The evidence indicates that the potentially adverse condition is not present.

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

Evaluation. Moab is the closest highly populated and densely populated area to the site and is approximately 53 kilometers (33 miles) away. As of 1980, Moab had a population density of 1,777.8 persons per square mile. However, there are no areas 1 mile by 1 mile with a population of 1,000 persons in proximity to the site.

The evidence indicates that the potentially adverse condition is not present.

6.2.1.2.4 Analysis of Disqualifying Conditions.

(1) Any surface facility would be located in a highly populated area.

Evaluation. The surface facility is not located in an incorporated place of 2,500 or more persons or any census designated place of 2,500 or more persons.

The evidence supports a finding that the site is not disqualified on the basis of that evidence and is not likely to be disqualified (Level 2).

(2) Any surface facility of a repository would be located adjacent to an area 1 mile by 1 mile having a population of not less than 1,000 individuals enumerated by the most recent U.S. Census.

Evaluation. The surface facility would be located 53 kilometers (33 miles) in air distance from Moab which is the nearest area of at least 1.6 by 1.6 kilometers (1 by 1 mile) having a population of not less than 1,000 individuals.

The evidence supports a finding that the site is not disqualified on the basis of that evidence and is not likely to be disqualified (Level 2).

> (3) The DOE could not develop an emergency preparedness program which meets the requirements specified in DOE Order 5500.3 (Reactor and Nonreactor Nuclear Facility Emergency Planning, Preparedness, and Response Program for Department of Energy) and related guides or, when issued by the NRC, in 10 CFR 60; Subpart I, Emergency Planning Criteria.

Evaluation. Since the issuance of the DOE Order 5500.3 in August 1981, the DOE has developed emergency preparedness programs for its facilities throughout the United States. Emergency preparedness programs have been developed for operations at the Nevada Test Site, which is an arid, remote area not dissimilar to the Paradox Basin site.

The recent experience of the DOE in emergency preparedness programs in response to the DOE Order 5500.3, and specifically the successful experiences at the Nevada Test Site (DOE 1982), indicate that the DOE will be able to develop an emergency preparedness program at the Davis Canyon site. Further, in its assessment of the requirements of this Order, the DOE has determined that it can prepare an emergency preparedness program. The "Emergency Planning Criteria," 10 CFR Part 60, Subpart I, has not been issued by NRC.

Therefore, the evidence does not support a finding that the site is disqualified (Level 1).

6.2.1.2.5 Conclusion for the Qualifying Condition. The major concern of this guideline is the protection of the public from the radiation doses in excess of the limits allowable under Section 960.5-(a)(1).

As shown in Section 6.4.1, the maximum exposed individual is expected to receive an annual dose of less than 2.0 millirem per year from all pathways (inhalation, submersion, and ingestion). This exposure is well below the regulatory limit of 25 millirems per year. Atmospheric dispersion can be expected to further reduce concentrations before released radionuclides are transported to the environment outside the restricted area.

Analyses of releases and exposures following closure have not been made, but are expected to be lower than operational values.

The annual radionuclide dose to a maximum exposed individual at the site boundary is several orders of magnitude below the allowable limit specified under 960.5-1(a)(1). Highly populated areas are distant from the site, so both of the qualifying conditions are met.

The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.2.1.3 Site Ownership and Control (Preclosure), Guideline 10 CFR 960.5-2-2.

Although the preclosure and the postclosure guidelines on site ownership and control are stated in similar terms (see Section 960.4-2-8-2), they are related to different System Guidelines (i.e., the preclosure and the postclosure System Guidelines). The land areas and controls required may differ slightly, as discussed in the preamble for Section 960.4-2-8-2.

This guideline includes a qualifying condition, one favorable condition, and one potentially adverse condition for analysis. It does not have a disqualifying condition.

6.2.1.3.1 Statement of Qualifying Condition.

> The site shall be located on land for which the DOE can obtain, in accordance with the requirements of 10 CFR Part 60.121, ownership, surface and subsurface rights, and control of access that are required in order

that potential surface and subsurface activities during repository operation and closure will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1).

Evaluation Process. The evaluation process involves the identification of the land requirements for site characterization and the repository, identification of the present ownership of the land, and an analysis as to whether the DOE can obtain the land requirements specified in the guideline. A summary of the evaluation is presented in Table 6-2.

Relevant Data. The land within the Davis Canyon site comprises approximately 92 percent public lands managed by the Bureau of Land Management (BLM), 4 percent State lands, and 4 percent private lands (Section 4.1). There are oil and gas leases, mineral leases, mining claims, and grazing rights including unrecorded stock-watering rights. No lands owned by the DOE are located in the vicinity of the candidate repository site.

Required land for site characterization activities, as well as methods of acquisition, are discussed in Sections 4.1 and 4.1.2.1. To summarize, the DOE will obtain land required for site characterization studies on public land under a cooperative agreement with the BLM. If these activities occur on privately owned land or State-owned land the DOE will purchase or lease required areas. The DOE will protect approximately 2,145 hectares (5,300 acres) of public land at the potential repository site by filing a withdrawal application for protection pursuant to the Federal Land Policy and Management Act of 1976 (43 USC Section 1714); 43 CFR Subpart 2310. The DOE expects to protect State and privately owned land by purchasing or leasing surface and subsurface rights.

Land requirements and current land use for the repository are fully discussed in Sections 3.4.1, 5.1, and 5.2.3. Current estimates are that a repository site will consist of (1) the geologic repository subsurface operations area of approximately 781 hectares (1,930 acres), (2) a fenced central area of about 189 hectares (467 acres) for support buildings and repository surface facilities, and (3) a controlled area extending outward from the edge of the underground facility. The total amount of land required for the surface facilities, subsurface facilities, and controlled area is estimated to be 2,332 hectares (5,760 acres).

It is anticipated that the repository site will be located on public, state, and private land. To comply with the NRC requirements, 10 CFR 60.121, Congressional action will be required to permanently withdraw the Federal land. State and private land will be acquired by voluntary purchase or Federal condemnation, if necessary.

Ownership of both surface and subsurface water rights is controlled by the State Engineer in Utah (Appropriation-Manner of Acquiring Water Rights, Utah Code Ann., Sections 73-3-1 et seq). As discussed in Chapter 3, the site is located in an arid region and there are no significant surface or subsurface water sources located at the site. Moreover, there are no recorded significant water rights approved by the Utah State Engineer at the site which would have to be acquired by the DOE (Utah State Engineer's Office of Water Rights, 1984).

Assumptions and Data Uncertainty. The number of acres constituting the controlled area is a conservative estimate based on available data. The actual size of the controlled area at the site will depend on the final rate of ground-water flow and other site characteristics, and will be established after completion of site characterization studies to ensure that releases to the accessible environment will not exceed those permitted by the EPA (40 CFR Part 191).

Analysis. As previously stated, public land required for site characterization can be obtained by a cooperative agreement and a withdrawal for protection. Required interests in private and State-owned lands can be acquired through purchase or lease. Condemnation can be used, if necessary. Land ownership requirements for the repository can be met by congressional action to permanently withdraw the required public lands. Required interests in State- and privately owned land can be obtained by negotiation of fee simple ownership of the surface and subsurface or by condemnation, if necessary.

6.2.1.3.2 Analysis of Favorable Condition.

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

Evaluation. The DOE does not presently own or control the land and all surface and subsurface mineral and water rights. The DOE will have to acquire the necessary rights as discussed above.

The evidence indicates that the favorable condition is not present.

6.2.1.3.3 Analysis of Potentially Adverse Condition.

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

Evaluation. The Davis Canyon site is located primarily on public land managed by the BLM. To acquire the necessary land, Congressional action is required to withdraw the land permanently.

The evidence indicates that the potentially adverse condition is present.

6.2.1.3.4 Analysis of Disqualifying Condition. The site ownership and control guideline does not have a disqualifying condition.

6.2.1.3.5 Conclusion for the Qualifying Condition. The favorable condition is not present. The DOE does not presently have ownership of the land, mineral, or water rights. The potentially adverse condition is present. However, the Davis Canyon site is located on land for which the DOE can obtain ownership, control access, and acquire the necessary rights including water to ensure that any site activities will not lead to a projection of radionuclide releases to an unrestricted area greater than those discussed in Section 960.5-1(a)(1) through negotiations or, if necessary, condemnation, and permanent withdrawal.

The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.2.1.4 Meteorology, Guideline 10 CFR 960.5-2-3

The principal objective of the preclosure guideline on meteorology is to ensure that the weather conditions at the site are favorable for the atmospheric dispersion of any radioactive emissions and to ensure compliance with the System Guideline for preclosure radiological safety. Also of concern is the potential for extreme weather phenomena that could affect the operation and safety of the repository.

This guideline includes a qualifying condition, one favorable condition, and two potentially adverse conditions for analysis. It does not have a disqualifying condition.

6.2.1.4.1 Qualifying Condition.

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

Evaluation Process. The approach for assessing compliance with this guideline is to show that the prevailing meteorological conditions at the site would act to transport and effectively disperse any radioactive emissions from the site to a potential receptor, such that the received whole body doses do not exceed the allowable limits. This evaluation process requires an understanding of the characteristics of the release rate and release height of

each radionuclide, dispersion data, the receptor location and number, the dose equivalent properties of the radionuclides released, dose assessments, a comparison of NRC release limits (10 CFR Part 20), and a comparison of the EPA whole body dose limits (40 CFR Part 191). The approach also assesses the potential for radiological emissions to be caused by a meteorologic event. This evaluation process requires an assessment of the frequency and intensity of extreme weather events, including tornadoes, hurricanes, flooding, rainstorms, snowstorms, maximum snowload, and high wind speeds. Both repository operation and closure are considered under normal operation (Section 6.4.1.2 and 6.4.1.3) as well as accident conditions (Section 6.4.1.4). A summary of the evaluation is presented in Table 6-2.

Relevant Data. The primary sources of data for this analysis are as follows:

1. Facility Design.. The design used in this analysis is presented in Section 5.1.

2. Preclosure Impact Assessment. A presentation of the expected and accidental sources of radionuclide releases, and an evaluation of the transport and diffusion of these releases, is presented in Section 6.4.1.

3. Meteorological Conditions and Assessment. No onsite or nearby representative wind speed, wind direction, or atmospheric stability data exist. These data are necessary to model predicted radionuclide transport and dispersion in unrestricted areas. Regional atmospheric stability data from the Grand Junction National Weather Station were used where appropriate (Section 3.4.3.1). In addition, regional severe weather data were used to conduct preliminary assessments (Section 3.4.3.6).

4. Demography. Population distribution and density are presented in Section 3.6.1.

Assumptions and Data Uncertainty. Long-term climatological and meteorological data at the Davis Canyon site are not available. A meteorological scenario that will result in maximum expected concentrations of radionuclides is assumed (i.e., very stable atmospheric conditions ["F" stability class] and very low wind speed [1 meter (3.3 feet) per second]).

The repository closure phase is not specifically discussed here. However, documentation of previous decommissioning studies of nuclear facilities indicates that, under any conditions, radioactive releases have been controlled to levels below those during the operations phase (see Section 6.4.1.1).

The data base on extreme weather phenomena that might be experienced in the area is typical of data that have been used to establish design parameters for other licensed nuclear facilities. Guidance on appropriate parameters to be considered is provided in Regulatory Guide 1.70 (NRC, 1978).

Analysis. Two types of evaluations were used to show compliance with the regulations specified in Sections 960.5-1(a)(1), 10 CFR Part 20 and 40 CFR Part 191, Subpart A. Both analyses are detailed in Section 6.4.1.

6.2.1.4.2 Analysis of Favorable Condition.

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

Evaluation. The analysis of atmospheric transport and diffusion indicates that relatively high mixing heights and moderate wind speeds prevail in the area of the site. Precipitation data are presented in Section 3.4.3.3. An analysis of 5 years of meteorological data (Holzworth, 1972, Figure 58, pp. 20-23) found approximately 193 episode-days in the region of the site (Grand Junction, Colorado), or approximately 39 episode-days per year (Section 3.4.3.1). In addition, dispersion of emissions can be hampered by the area's

terrain; local inversions can cause the air to be trapped in valleys. However, because of the influence of the rugged surrounding terrain on the micrometeorology of the site and the potential for local inversions to trap emissions in valleys, a condition of favorability cannot be found.

The evidence indicates that the favorable condition is not present.

6.2.1.4.3 Analysis of Potentially Adverse Conditions

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

Evaluation. The average population density in the region is 3.8 persons per square mile (Section 6.2.1.2.2). The region for which the population-exposure rate is calculated includes Utah and Colorado counties within a 80-kilometer (50-mile) radius of the site. The prevailing wind direction in the area is from the southwest (Section 3.4.3.4). Based upon a 22.5 downwind sector and U.S. Geologic Survey 1:250,000 topographic maps, the nearest populated locality downwind of the site is La Sal Junction, at 31 kilometers (19 miles). While the population at La Sal Junction is small and not officially enumerated, the DOE assumes that the population density exceeds that of the region and finds the potentially adverse condition to be present. Since the intent of this guideline is to address the prevailing wind, the 50 percent wind direction sector used in the draft environmental assessment was abandoned in favor of this smaller section dimension. The presence of this locality downwind of the facility is sufficient to find the adverse condition present. Preliminary radiological analyses of emissions are presented in Section 6.4.1.

The evidence indicates that the potentially adverse condition is present.

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

Evaluation. The frequencies of extreme weather phenomena in the site area are discussed in Section 3.4.3.3. Tornadoes are infrequent in Utah. Only 32 tornadoes were sighted in the entire State between 1953 and 1980. The recurrence interval for tornadoes at the site is about 13,000 years based on a 1-degree-square area surrounding the site. On the average, the site area can expect thunderstorms about 45 days per year, hail 3 days per year, freezing rain 2 days per year, and heavy fog 10 days per year. Snowfall (2.54 centimeters [1.0 inch] or more) occurs 10 to 20 days per year in the site area. The repository will be designed to allow safe operation during these periods of extreme weather; however, some material shipments and work-force commutes could be disrupted.

The evidence indicates that the potentially adverse condition is present.

6.2.1.4.4 Analysis of Disqualifying Condition. The meteorological guideline has no disqualifying condition.

6.2.1.4.5 Conclusion for the Qualifying Condition. The requirements of the qualifying condition of this guideline are that the radionuclide releases to an unrestricted area are not likely to be greater than those allowable under the requirements of 10 CFR 960.5-1(a)(1), or specifically, that releases and dispersion meet the requirements of the following:

- 10 CFR Part 20
- 10 CFR Part 60
- 40 CFR Part 191.

An analysis was conducted for each requirement.

The first evaluation (Section 6.4.1) shows that repository operation and closure will result in radionuclide concentrations of less than 6.0 percent of the 10 CFR Part 20 limits

for releases to the unrestricted environment. Atmospheric dispersion can be expected to further reduce concentrations before released radionuclides are transported to the environment.

The second evaluation shows that the maximum exposed individual is expected to receive an annual dose of 1.8 millirem per year, from all pathways (inhalation, submersion, and ingestion). This exposure is below the regulatory limit of 25 millirem per year.

The severe weather conditions the site may sustain, including flooding, are deemed potentially adverse. This is not perceived to be a significant problem, however. Facilities have been designed to mitigate the forces and conditions involved.

The meteorology at the site, even under inversion conditions, will effectively disperse radioactive concentrations to safe levels before leaving the site. Thus, population centers down wind from the facility will be adequately protected (Section 6.4.1.4).

The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.2.1.5 Offsite Installations and Operations, Guideline 10 CFR 960.5-2-4

The preclosure Technical Guideline on offsite installations and operations has two objectives: (1) to ensure that the impacts of any nearby industrial, transportation, military, and atomic energy defense installations and operations on repository siting, construction, operation, closure, and decommissioning are adequately considered; and (2) to ensure that any radionuclide emissions from such installations, when combined with preclosure emissions from the repository, would not lead to total radiological exposures in any unrestricted area greater than those allowed by the requirements specified in the pertinent System Guideline.

This guideline includes a qualifying condition, one favorable condition, and two potentially adverse conditions for analysis. It also has one disqualifying condition.

6.2.1.5.1 Statement of Qualifying Condition.

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

Evaluation process. This section discusses the process used to determine whether the qualifying condition can be met by a repository at the Davis Canyon site. The data, assumptions, and method of analysis used to derive the findings in subsequent sections are described below.

Offsite facilities or operations are considered hazardous if potential accidents at an offsite location might jeopardize the safety of the repository or its staff (NRC, 1978, Regulatory Guide 1.91). Examples of hazards that might be produced by accidents at offsite installations or operations are:

- Shock Waves
- Missiles
- Incendiary Fragments
- Flammable Vapor Clouds
- Toxic Chemical Clouds.

Relevant Data. Data relevant to the evaluation of this guideline include (1) proximity of nearby hazardous facilities and operations and identification of the type of hazards they could pose to a repository, and (2) proximity of and radioactive emissions from other nuclear facilities or operations near the site.

Data are provided in Section 3.5 and in the comparative evaluation information base (ONWI, 1984) for the facilities or operations listed below which exist within 8 kilometers 5 miles) of the potential repository operations area. For each entry, the associated potential hazard is indicated below.

- Chemical plants (fire, explosion, and toxic hazards)
- Refineries (fire, explosion, and toxic hazards)
- Mining and quarrying operations (explosion)
- Oil and gas wells (explosion and fire)
- Gas and petroleum storage installations (fire, explosion, and toxic hazard)
- Military munitions storage areas (explosion)
- Military operations (explosion)
- Airports (aircraft crash and fire)
- Transportation of hazardous materials by the following modes:
  - Waterway (explosion and toxic hazards)
  - Railroad (explosion and toxic hazards)
  - Highway (explosion and toxic hazards)
  - Pipeline (explosion)
  - Aircraft (crash).

Existing nuclear facilities and operations are identified in the analysis of the favorable and adverse conditions. If the emissions are known they are also provided.

Assumptions and Data Uncertainty. An underlying assumption of the evaluation is that the hazards identified by NRC (1978) in Regulatory Guide 1.70 for nuclear power plants are the same hazards that should be of concern for repositories. Further, the NRC and utility applicants have performed analyses that are used to establish the repository's degree of vulnerability to such hazards. The analysis assumes that repository facilities will be designed and constructed to the same standards of safety as for nuclear power plants (e.g., waste handling building will be tornado proof).

The term "nearby" for evaluation of hazardous installations under this guideline is defined in the NRC (1975) Regulatory Guide 4.7 (for located nuclear facilities) as being within an 8 kilometer (5-mile) radius of the site. When assessing the potential for cumulative radiological impacts of the repository combined with other nuclear facilities in the locality, an 80-kilometer (50-mile) radius from the repository was used (NRC, 1976, Regulatory Guide 4.2).

Analysis. Analyses of explosive hazards, toxic hazards, airplane crashes, and radioactive releases were performed as described below. If one or more hazards were identified, a potentially adverse condition is present.

Explosive Hazards. The procedures adopted by NRC (1978) in Regulatory Guide 1.91 provide for the evaluation of safe standoff distances by comparison of explosive hazards to the equivalent hazard of TNT. For solid substances not intended for use as explosives but subject to accidental detonation, the NRC states that it is conservative to assume that the solid material is equivalent to TNT on a mass basis (100 percent equivalency).

The NRC further states that the maximum probable explosive cargo for a highway truck is 22,680 kilograms (50,000 pounds), and for a railroad box car is 59,875 kilograms (132,000 pounds). Based on these TNT equivalents, a safe standoff distance from a public highway on which TNT may be transported is 610 meters (2,000 feet), and from a railroad is 914 meters (3,000 feet). The overpressures at these distances would be below repository design levels.

Toxic Hazards. A determination was made as to whether any source of toxic hazards will be located within 8 kilometers (5 miles) of the repository site (NRC, 1975, Regulatory Guide 4.7). If a source of toxic hazard exists such as a rail line on which toxic chemicals like chlorine are carried, a potentially adverse condition is found. It was determined that no source (e.g., chemical plant, refinery, or state highway) exists within 5 miles of the site.

Airplane Crashes. Three general subdivisions of airspace are considered. In the first, uncontrolled airspace, air traffic above the site is so infrequent that the NRC does not consider the risk to be sufficiently credible to warrant attention. In the second, the site lies near controlled airways, and is subject to risk from in-flight crash rates for aircraft using the airways, the number of flights per year, the effective critical area of the unit (square kilometers or miles), and the inverse of the width of the airway. Using TVA (Tennessee Valley Authority) (1976) data of 5 by 10^{-10} crashes per mile, 10,000 flights per year, an effective critical area of 0.008 square kilometer (0.003 square mile), and an airway width of 14.8 kilometers (9.2 miles), the annual probability would be 1.6 by 10^{-9} per year, or approximately 1/100 of the NRC level for credible accidents. The third subdivision is takeoffs and landings, which require another methodology. Because the Davis Canyon site is not within a takeoff or landing path (NOAA, 1984), this subdivision is not discussed further.

Due to the low probability of an in-flight crash, the risk to repository activities is considered to be negligible and is not evaluated further.

Radioactive Releases. If releases from nuclear facilities or operations nearest the site are regulated to 10 CFR Part 20 standards and are greater than 80 kilometers (50 miles) from the repository, no calculation of emissions was made because any contributing releases would be negligible to zero. The analysis in Section 6.4.1 indicates that doses from the repository operations would be orders of magnitude below natural background levels, and maximum individual doses from accidental releases would be 1/10,000 the dose that would be received by the same individual from natural background radiation at the same geographical location.

In the analysis of favorable and adverse conditions, the dose from other facilities or operations within 80 kilometers (50 miles) was added to the dose received from a repository direction without taking credit for the dispersion that will occur between the boundaries of the facilities.

6.2.1.5.2 Analysis of Favorable Condition.

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

Evaluation. There are three uranium mills contributing to radioactive releases within 80 kilometers (50 miles) of the Davis Canyon site. The Moab Uranium Mill is located in Moab, approximately 53 kilometers (33 miles) northeast of the site. The White Mesa Uranium Mill is 8 kilometers (5 miles) south of Blanding, and 58 kilometers (36 miles) from the site, and the Lisbon Mill is located in the Lisbon Valley, approximately 48 kilometers (30 miles) east of the site (Section 3.2.8.2). When operating, the radioactive releases from the Moab mill are such that the maximum whole body dose, to which the nearest permanent resident (0.8 kilometer [0.5 mile] east of the mill) is exposed, is 2.0 millirem per year (NRC, 1979, NUREG-0453, p. 4-8). Releases from the White Mesa mill result in a maximum whole body dose, to which the nearest permanent resident (1.9 kilometers [1.2 miles] north of the mill) is exposed, of 5.8 millirem per year (NRC, 1979, NUREG-0556, p. 4-12). These doses include contributions from radon-222 and its daughters. Releases from any one of these mills result in a maximum whole body dose of 6.3 millirems per year to the nearest permanent resident (1.6 kilometers [1 mile] north of the mill)(Rio Algom Corp., 1985). While this release is well below EPA standards, the presence of any one of these mills is sufficient for the favorable condition not to be found. These radioactive releases must be considered under the requirements of 40 CFR 191.

The evidence indicates that the favorable condition is not present.

6.2.1.5.3 Analysis of Potentially Adverse Conditions

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

Evaluation. No potentially hazardous installations or operations exist close to the site.

There are no chemical plants, refineries, military munitions storage areas, or railroads within 8 kilometers (5 miles) of the site (ONWI, 1984).

No oil or gas wells or gas and petroleum installations are located within 8 kilometers (5 miles) of the site (Section 3.2.8.1).

The site is more than 56 kilometers (35 miles) from the airports in Blanding and the airport north of Moab (Section 3.5.3) and 29 kilometers (18 miles) from the San Juan County Airport at Monticello. The state highway nearest the site is located more than 8 kilometers (5 miles) away (Section 3.5.1).

There are no known private or public airstrips within 8 kilometers (5 miles) of the Davis Canyon site. The airstrip at Canyonlands Resort is about 10 kilometers (6 miles) from the site.

Because no sources of toxic materials are known to exist within 8 kilometers (5 miles), it is expected that no toxic clouds would form that could threaten the safety of the site (ONWI, 1984).

The evidence indicates that the potentially adverse condition is not present.

(2) Presence of other nuclear installations and operations, subject to the requirements of 40 CFR Part 190 (EPA, 1982b) or 40 CFR 191, Subpart A, with actual or projected releases near the maximum value permissible under those standards.

Evaluation. Three uranium mill sites occur within 80 kilometers (50 miles) of the site. Radioactive releases from the mills when operating result in a dose to the maximum exposed individual of only 25 percent of that permitted under the standards.

The evidence indicates that the potentially adverse condition is not present.

6.2.1.5.4 Analysis of Disqualifying Condition.

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

Evaluation. There are no atomic energy defense facilities in proximity of the site (ONWI, 1984a).

The evidence does not support a finding that the site is disqualified (Level 1).

6.2.1.5.5 Conclusion for the Qualifying Condition.

Evaluation. No potentially adverse conditions related to offsite installations and operations at the site would detract from preclosure radiological safety. No nearby industrial, transportation, or military installations or operations are so close to the site that they will significantly affect repository siting, construction, operation, closure, or decommissioning. The nearest possible sources of emissions lie within 80 kilometers

(50 miles) of the site, but it was shown that emissions from these sources, combined with any potential releases from the repository, would not result in releases to unrestricted areas greater than those allowed by 10 CFR Part 20, 10 CFR Part 60, and 40 CFR Part 191.

The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.2.1.6 Environmental Quality, Technical Guideline 10 CFR 960.5-2-5

The objectives of the environmental quality guideline are to ensure that the quality of the environment will be adequately protected throughout all stages of the program, and that adverse impacts will be mitigated to an acceptable degree, given programmatic, technical, and other factors. This guideline addresses these issues by identifying the ways in which potential sites will qualify and be disqualified based on environmental criteria, and identifying specific favorable and potentially adverse conditions.

This guideline includes a qualifying condition, two favorable conditions, and six potentially adverse conditions for analysis. It also has three disqualifying conditions.

6.2.1.6.1 Statement of Qualifying Condition

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

Evaluation Process. This section discusses the methods used to determine whether the qualifying condition can be met by a repository at the Davis Canyon site. The data, assumptions and method of analysis used to reach the findings in subsequent sections are described below. A summary of this evaluation, along with summaries for socioeconomic and transportation guidelines, are presented in Table 6-2.

Relevant Data. Statutes and other regulatory requirements promulgated for the protection of the environment are integral to evaluations of this guideline. Federal statutes, the State statutes for which the Federal statute mandates compliance, Executive Orders, and implementing regulations that are potentially applicable to the DOE's activities at the proposed repository site, are listed in Table 6-3. The table also presents the purpose and intent of each authority, the requirements for compliance, the actions taken or planned by the DOE to demonstrate compliance, and the DOE's projected ability to comply with the regulatory requirements.

Table 6-4 lists nonfederally derived State and local environmental requirements. The Department intends to comply with all State and local environmental requirements not inconsistent with our responsibilities under the NWPA. The DOE intends to consult with State and local officials, concerning sites that are recommended, to determine the scope of the above noted requirements and to identify other regulations as appropriate.

The physical and environmental setting of the site is described in Section 3.4. Descriptions of the proposed activities associated with site characterization, repository construction, operation, closure, and decommissioning are presented in Sections 4.1 and 5.1. The assessment of the environmental impacts of the proposed activities associated with site characterization and with repository construction, operation, closure, and decommissioning is presented in Sections 4.2 and 5.2.

Table 6-5 summarizes the potentially significant adverse environmental impacts from site characterization and repository construction; Table 6-5 also summarizes planned control measures to be employed to minimize such impacts. The projected effectiveness of the control measures and the acceptability of any residual impacts are also described. Control measures

presented are representative of the types that have been generally accepted and widely used for similar projects. Other control measures may be identified or required depending on the results of the ongoing analyses. Where this tabular information summarizes presentations in previous chapters, cross-references are provided.

Assumptions and Data Uncertainty. The environmental data used in these analyses are based on several site-specific, area, and regional studies. In some cases, application of the data base to this site involves assumptions about the similarity of the site to the surrounding region. These assumptions often involve projections about the outcome of environmental data gathering based on the DOE's current understanding of area and regional information. Bounding and conservative assumptions of site conditions or project activities have been made where appropriate and are addressed in Chapters 4 and 5. Information used in the analysis regarding regulatory requirements is derived from legislative acts, executive orders, and attendant implementing regulations. The analysis is thus a projection of expected compliance with referenced environmental requirements.

Projected ability to comply with regulatory requirements assumes that compliance activities can be completed (1) within normal regulatory agency review time periods, and (2) without unusual information requirements by regulatory agencies. Ability to comply with these requirements is also dependent on the utilization of existing engineering technology and construction methods to achieve standards of environmental control which are implicit in the compliance projections.

Analysis. The analysis considers statutory requirements, significant adverse impacts and their mitigation, and proximity of project activities to protected resources.

The evaluation of projected ability to meet statutory requirements is based on an assessment of the degree to which the existing data and assumptions about the use of available engineering technology and construction methods indicate an ability to comply with the substantive and procedural provisions of applicable statutes, orders, and regulations and the DOE's judgment as to its probable ability to comply with the overall requirements. Projected ability to comply with specific statutes is indicated (Table 6-3) when it is likely, based on the assessments, that the DOE will be able to meet all requirements, or that the requirements are not applicable to the proposed activities at the site. A favorable condition exists if a projected ability to comply is found. A potentially adverse condition exists if a major conflict with these requirements is projected. Table 6-4 lists nonfederally derived State statutes.

Environmental impacts of site characterization activities and repository construction, operation, decommissioning, and closure are present in Chapters 4 and 5. Impacts that are considered potentially significant and adverse are summarized in Table 6-5. Control measures that the project will use to mitigate impacts, and their projected effectiveness, are also presented in Table 6-5.

In this analysis, a favorable condition is present if potentially significant adverse environmental impacts can be mitigated to an insignificant level. A potentially adverse condition is present if such impacts cannot be avoided or mitigated. A disqualifying condition is present if such impacts could not be mitigated to an acceptable degree or if the quality of the environment in the affected area could not be adequately protected.

Evaluations of the disqualifying conditions also include (1) assessing the location of the site and repository support facilities with respect to boundaries of components of the national and State park systems, wildlife refuges, wilderness preservation areas, forest land, and wild and scenic rivers; and (2) assessing whether the activities would constitute an irreconcilable conflict between the facilities and the previously designated resource preservation use of such components.

Table 6-3. Environmental Statutory/Regulatory Authorities and Requirements, Davis Canyon

Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
National Environmental Policy Act of 1969, 42 USC Sections 4321-4361 (NEPA) (40 CFR Part 1500) (as directed in Nuclear Waste Policy Act of 1982 (NWPA)(42 USC Sections 10101 et seq.)	To establish a national policy that will encourage productive and enjoyable harmony between people and their environment and to promote efforts to prevent or eliminate damage to the environment.	• This Act requires Federal agencies to assess the environmental impacts of major Federal actions significantly affecting the quality of the human environment. • The NWPA establishes that site characterization activities are preliminary actions that do not require an environmental impact statement (EIS). Statutory environmental assessments are required for site nomination. An EIS is required for repository site recommendation. The NWPA provides that certain standard EIS content requirements need not be included.	This document is the statutory EA under NWPA. The DOE plans to prepare an EIS in accordance with NEPA as specified in NWPA. Pursuant to NWPA, no NEPA document is required for site nomination, recommendation, or characterization.	The DOE projects an ability to comply because it will prepare the required NEPA EIS.
Land Use				
Materials Act of 1947, 30 USC Sections 601-604 (43 CFR Part 3620)	To remove common types of sand, gravel, and stone from coverage of mining laws.	A free use permit is required from the Bureau of Land Management (BLM) if the DOE plans to take sand, gravel, stone, or other common materials from BLM land.	• The DOE will determine the need for sand, gravel, stone, or other common material in the development of a potential repository. • The DOE will apply to BLM for a permit to use sand, gravel, and other material if needed.	• The DOE projects an ability to comply with BLM permit requirements for site characterization and repository phases and will provide BLM with any information requested. • Act would not apply to materials extracted from the site once land transfer from the BLM to the DOE is complete.
Coastal Barrier Resources Act, 16 USC Sections 3501-3510	To prohibit new Federal expenditures for construction of projects within the Coastal Barrier Resources System (CBRS), which consists of undeveloped coastal land along the Atlantic and Gulf Coasts and adjacent wetlands and inlets.	The DOE must determine if project area or related activities are within the CBRS. If so, site and activities must be abandoned.	Proposed project activities have been analyzed against the requirements of this statute. No activity related to a repository in Davis Canyon, including salt disposal, is proposed in areas covered by the Act.	This Act is not applicable because no activities are proposed within coastal barriers (Section 3.1).

Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Coastal Zone Management Act of 1972, 16 USC Sections 1451-1464 (15 CFR Part 930)	To ensure that any Federal project in the coastal zone of a State, or directly affecting the coastal zone, is consistent with approved State management programs.	• The DOE must determine if project activities are in, or could affect, the coastal zone of a State. • If the DOE determines that a coastal zone is affected, the DOE must determine if the State involved has a Coastal Zone Management Program (CZMP) approved by the Secretary of Commerce. • The DOE must review the State CZMP and consult with the State agency responsible for the CZMP, and perform a consistency determination. • The DOE must obtain concurrence from the State with the DOE's consistency determination for project to proceed. • The DOE must initiate activities to determine if offshore disposal would be consistent with the approved State CZMP.	The requirements of this statute have been analyzed against proposed project activities. No activity related to the repository including salt disposal will affect areas covered by this Act.	This Act is not applicable because no coastal resources will be affected (Section 3.1). Ocean dumping of excess mined salt is not a preferred method of disposal for the Davis Canyon site (Sections 4.2.1.11.3 and 5.2.10.3).
Marine Protection, Research and Sanctuaries Act of 1972, 33 USC Sections 1401-1444 (40 CFR Parts 220-228)	To regulate the dumping into ocean waters of all types of materials.	If the DOE decides to dispose of salt in the ocean, a permit is required.	The DOE considers the ocean disposal of waste salt a remote option.	Should the DOE select ocean disposal of salt as a preferred method, applicable regulations will be followed, including obtaining a permit.
Wild and Scenic Rivers Act, 16 USC Sections 1271-1287	To prohibit construction on or directly affecting any river that is designated a component of the National Wild and Scenic River (NWSR) system or on any river designated for addition to the system that would adversely affect the values of NWSR system.	• The DOE must determine if any rivers in the vicinity of the project area are designated as a component of the NWSR system or a potential addition to system. • If the DOE finds a NWSR in vicinity, it must prepare an impact evaluation. • If impacts are direct and adverse, the DOE must advise the Secretary of Interior and Congress.	Consultation with the U.S. Department of the Interior (DOI) has determined that no designated NWSR or potential addition to system is located in the project area. No part of the Colorado River in Utah is designated as a wild and scenic river. (Strait, 1984).	Act is not applicable because no designated NWSR or potential addition to the system exists in the project area.

Table 6-3. Environmental Statutory/Regulatory Authorities and Requirements, Davis Canyon
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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Wilderness Act, 16 USC Sections 1131-1136 (Federal Land Policy and Management Act of 1976, 43 USC Section 1782), (36 CFR 261.16 and 293.15; 43 CFR Parts 19, 3802, and 8560; 50 CFR Part 35)	To establish a National Wilderness Preservation System for public recreational, scenic, scientific, educational, conservation, and historical use.	• Roads, structures, installations, etc. are prohibited in designated Wilderness areas or Wilderness Study Areas (WSAs). • The DOE must avoid siting repository and repository access within Wilderness Areas, as well as within WSAs until Congress has made a final determination whether to include them permanently as Wilderness Areas.	• No designated Wilderness Areas have been identified in the project area. However, three BLM WSAs, one U.S. Forest Service Wilderness Area, and one National Park Service (NPS) proposed wilderness area occur in the vicinity. The Dark Canyon Wilderness, administered by U.S. Forest Service is 40 kilometers (25 miles) northeast of the northeast of the site. Indian Creek WSA, abutting Canyonlands National Park and west of Needles Overlook, and Butler Wash WSA abutting the Needles District of Canyonlands National Park on the south, are 11 kilometers (7 miles) northwest and 10 kilometers (6 miles) southeast of the site respectively. The Bridger Jack Mesa WSA, which abutts Lavender Canyon on one side, is 5 kilometers (3 miles) east of the Davis Canyon site (Section 3.4.1) (BLM, 1980; 1982). The WSAs are subject to protection under the Federal Land Policy and Management Act. The proposed Needles unit in Canyonlands National Park extends to the eastern boundary of the park and is in close proximity (0.3 km) to the project area (Parry, 1985) (Section 3.4.1).	The DOE projects an ability to comply because no facilities are located within designated Wilderness Areas proposed wilderness areas, or WSAs. Based on the analysis in Sections 4.2 and 5.2, it is anticipated that a portion of the proposed Wilderness Area within Canyonlands National Park and the Bridger Jack Mesa Wilderness Study area will experience some project noise. However, no activities are planned that would impair the suitability of proposed wilderness areas or WSAs for preservation as wilderness.

Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Objects Affecting Navigable Airspace, 49 USC Section 1501 (14 CFR Part 77)	To prevent construction of structures that would be a hazard to air navigation and regulate other structures that could affect air navigation.	• The DOE must notify the Federal Aviation Administration (FAA), using FAA Form 7460-1, of (1) plans to construct any structure 61 meters (200 feet) or greater in height; (2) plans to construct any structure within a 100 to 1 slope at 6,906 kilometers (20,000-feet) distance (50 to 1 slope at 3,048 meters [10,000 feet] distance) of runway of public or military airport; and (3) plans to construct any structure within an instrument approach area. • The DOE must comply with FAA's response to notification, which may include lighting and marking structure according to FAA specifications.	o The DOE has determined that FAA notification is necessary because repository shaft headframe will exceed 61 m (200 ft) in height (Section 5.1.1.3). No structure will be within 6,096 m (20,000 ft) of a public or military runway, or within instrument approach area (Section 3.5.3). • The DOE will submit FAA Form 7460-1 notifying FAA of plans to construct an 81 m (265 ft) service shaft headframe and comply with any FAA instructions or request for additional information or submittals.	The DOE projects an ability to comply because submitting FAA forms and following FAA specifications or design modifications will satisfy requirements.
Federal Land Policy and Management Act of 1976, 43 USC Sections 1701-1782 (36 CFR Part 251; 43 CFR Parts 2300 and 2800)	To authorize and establish procedures for Federal Departments and Agencies to use, occupy, and develop Federal lands, including public lands administered by the Department of Interior (DOI), and BLM and Forest Service lands administered by the Department of Agriculture. These mechanisms are rights-of-way, withdrawals, and cooperative agreements.	• If site characterization occurs on DOI or BLM managed lands, the DOE Secretary may negotiate and execute a cooperative agreement with the Department of the Interior and apply for required rights-of-way. The DOE must follow withdrawal procedures to protect the land. These procedures include: preapplication consultation with the BLM, submission of application, and preparation of resource management plan and implementation plan. The Secretary of Interior can authorize withdrawals up to 20 years. Withdrawals of 5,000 or more acres are subject to Congressional review. In conducting the	• Portions of the project are located on BLM land (BLM 1982). There is no U.S. Forest Service land in the area (Butt, 1985) (Section 3.4.1). • The DOE has a Memorandum of Understanding (BLM, 1984) with the BLM whereby the BLM agrees to the use of a cooperative agreement for site characterization studies. The DOE will execute a cooperative agreement with the BLM. To protect the potential site the DOE will consult with the BLM, prepare or assist in preparing a resource management plan and implementation program, and will file an administrative withdrawal application. The DOE will comply with its	• The DOE projects an ability to comply for site characterization because impacts have been evaluated herein, including impacts to protected lands such as WSAs and Canyonlands National Park (Sections 4.2, 5.2, 5.3), and because the DOE will enter into a cooperative agreement with BLM for authorization to conduct site characterization activities and withdraw land for protection (according to Memorandum of Understanding between the DOE and the BLM). • This Act does not apply to the permanent transfer of land to the DOE for the repository; such a transfer must be approved by Congress.

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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Federal Land Policy and Management Act (Continued)		withdrawal activities, the DOE must comply with its internal procedural requirements set forth in DOE Real Estate (Real Property) Management Order (DOE 4300.1A). • If Forest Service land is involved, rights-of-way may be required. • If the repository were to be on DOI or BLM managed lands, an Act of Congress will be required for permanent withdrawal or transfer, and FLPMA will not be applicable.	internal order regarding real property acquisition. If repository site will be located on DOI or BLM managed lands, the DOE will pursue Congressional approval.	
Taylor Grazing Act, 43 USC Sections 315-316o. (43 CFR Part 4100)	To create, protect and regulate Federal grazing districts, and to provide for the orderly use and development of rangeland.	If repository site or access is located on a BLM designated grazing allotment, the DOE must secure right-of-way or withdrawal of grazing district land from the BLM in accordance with FLPMA.	Candidate repository site and access corridors are located on BLM land (BLM, 1982) (Section 3.4.1). Site is within BLM-Moab designated grazing allotments (Nodine, 1985). The DOE will apply for right-of-way or seek withdrawal under the Federal Land Policy and Management Act.	The DOE projects an ability to comply because it will request withdrawal of site land within the grazing allotment, and because it will comply with procedural requirements of this Act and provide BLM with any information requested (Section 3.4.1.3.1).
National Trails System Act, 16 USC Sections 1241-1251	To establish and protect National Recreation, National Scenic, and National Historic Trails.	If a National Trail is located within the project area, the DOE must determine if the project would be incompatible with the purposes of the trail. Relocation of a trail may be possible if repository characterization, construction, or operation is found to be incompatible with the purposes of the trail; substantial relocation requires an Act of Congress.	Consultation with the DOI and review of published lists of National Trails has determined that no National Trails exist in the project area (Strait, 1984; NPS, 1984; NPS, 1983). The Old Spanish Trail is not a designated or potential National Trail (Strait, 1984).	This Act is not applicable because no designated or potential National Trails exist in the project area.

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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
National Forest Organic Legislation, 16 USC Section 471a et seq.; Multiple-Use Sustained-Yield Act of 1960, 16 USC Sections 528-531; Forest and Rangeland Renewable Resources Planning and Research Acts, National Forest Management Act, and Renewable Resources Extension Act, 16 USC Sections 1600-1676 (36 CFR Part 261)	To protect and improve National Forests, which are established for outdoor recreation, range, timber, watershed, and fish and wildlife purposes.	• The DOE must obtain Congressional approval for withdrawal or transfer of National Forest land for DOE use as repository site. • Access roads on National Forest land must be built in accordance with requirements defined by the Department of Agriculture. Permanent roads must be approved as part of National Forest Transportation System. A special use permit may be required for site characterization activities.	The DOE has determined that no National Forest System land occurs in project area (Butt, 1985) (Section 3.4.1). The Manti-La Sal National Forest is 15.4 kilometers (9 miles) south of the site.	Statutes are not applicable because no National Forest land occurs in the project area.
Organic Act of the National Park Service, 16 USC Section 1; National Park System Mining Regulation Act, 16 USC Sections 1901-1912 (36 CFR Part 9)	To preserve National Parks and to leave them unimpaired for future generations with special emphasis on halting or regulating mining so as to prevent or minimize damage to the environmental resources.	• The DOE should not locate the restricted area or repository support facilities on land within a National Park.	The DOE has determined that the candidate repository site and support facilities do not lie within a National Park (Sections 3.4.1; 4.1.2.1). The nearest approach of the controlled area boundary is 0.3 km (0.2 mi) from the Canyonlands National Park boundary (Canyonlands National Park Act, 16 USC Section 271-271g). The potential impact to the park is assessed in Sections 4.4.1 and 5.5.1 using the park values described in 16 USC Section 271.	This Act is not applicable because the restricted area or repository support facilities will not lie within a National Park and any expected impacts to Canyonlands National Park will be mitigated to an acceptable level (Sections 4.2 and 5.2).
Farmland Protection Policy Act, 7 USC Sections 4201-4209 (7 CFR Part 658)	To minimize the extent to which Federal programs contribute to the unnecessary and irreversible conversion of farmland to nonagricultural uses.	• The DOE must complete first part of Soil Conservation Service (SCS) Form AD1006 and submit to SCS. • If SCS determines that prime farmland exists on site, the DOE must complete a site assessment using criteria set forth in 7 CFR Part 658 or State criteria where they exist.	The DOE has completed first part of Form AD1006 and submitted it to SCS. SCS has determined that there are no prime or unique soils in the project area (Holt, 1985).	This Act is not applicable because no prime or unique farmland soils exist in the project area.

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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Farmland Protection Policy Act (Cont.)		• If a final threshold score is exceeded, the DOE must consider mitigating measures to protect the prime farmland and assure, to extent practicable. project compatibility with State and local programs and policies.		
Floodplain/Wetlands Executive Orders, E.O. 11988 and E.O. 11990 (10 CFR Part 1022)	To require Federal agencies to implement regulations that will protect wetlands and minimize effects from development in floodplains. The DOE implementing regulations are contained in 10 CFR Part 1022.	• The DOE must determine if wetlands or floodplains occur in project area. If floodplains or wetlands are found to occur in project area, the DOE must publish notice in Federal Register, notify Federal, State, and local agencies of proposed action, prepare an assessment of proposed action (floodplain/wetlands assessment), which includes alternative measures to minimize impacts if the project proceeds in the floodplain/wetlands, and publish a statement of findings. • The DOE actions in floodplains must be designed to minimize harm to floodplains. • Construction in a floodplain must be in accordance with Federal Insurance Administration regulations. • The DOE should avoid construction in a wetland unless there is no practical alternative.	• The DOE has determined that a portion of candidate repository site is within a 100-year floodplain (Weddell, 1984) (Section 3.3.1.4). • A description of the potential impacts to floodplains is including in Section 4.2.1.2.4. • Preliminary determination has been made that no wetlands exist on the candidate repository site but may exist within repository road and railroad access routes (Johnson, 1985) (Section 3.4.2.2). • A Federal Register notice of the DOE's proposed floodplain/wetlands assessment giving the opportunity for public comment will be published should the site be recommended for characterization. • The DOE will publish a statement of findings subsequent to the public comment period. Section 4.2.1.2.4 provides a description of existing wetlands and floodplains, proposed actions, an assessment of impacts, and a discussion of alternatives and mitigative measures.	• The DOE projects the ability to comply with its requirements under 10 CFR Part 1022 because "DOE has reevaluated the practicability of the proposed floodplains/wetlands actions taking into account public comments received. and will continue to evaluate practicable alternatives with applicable agency representatives. DOE has taken into account mitigating measures and has designed the proposed floodplain actions to minimize potential harm to or within the floodplain. No State and local applicable floodplain standards exist. • The DOE projects an ability to comply with wetlands requirements, because no wetlands exist onsite and wetlands can be avoided, or impacts on them mitigated, through careful siting of repository road and railroad alignments.
Department of Transportation Acts, 49 USC Section 303, 23 USC Section 138.	To preserve the natural beauty of the countryside. public parks, recreation lands, wildlife and waterfowl refuges,	The Secretary of Transportation may only approve a transportation project requiring the use of publicly owned	Although the Acts do not impose any requirements directly on the DOE. the DOE will consult with the De-	The DOE projects an ability to comply because it will consult with the Department of Transportation and consider alternatives and mitigation.

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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Department of Transportation Acts (Continued)		waterfowl refuge of significance or the use of land containing an historic site of significance if there is no prudent and feasible alternative and mitigation planning is included.	of these Acts to plans for upgrading Federal roads or Federal-aid highways and for constructing a bridge across the Colorado River.	
Waste Disposal				
Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), 42 USC Sections 9601-9657	To impose notification requirements and liability for unpermitted releases of hazardous substances, and to establish a fund for remedial use in case of release of hazardous substances.	The U.S. Environmental Protection Agency (EPA) must be notified in event of a reportable release of a designated hazardous material.	Small quantities of generated hazardous wastes (e.g., used motor oil, solvents, cleaners) will be collected and transported to an offsite facility licensed to receive such wastes. The DOE will comply with all notification requirements.	The DOE projects the ability to comply because the DOE will comply with all notification requirements in the event of an accidental release.
Hazardous Materials Transportation Act, 49 USC Sections 1801-1812 (49 CFR Parts 171-178)	To give additional regulatory and enforcement authorities to the Secretary of Transportation to protect the nation from risks of transporting hazardous materials.	Regulations define packaging, labeling, handling, documenting, and transporting requirements for hazardous materials, including notification procedures in the event of a spill.	The DOE will comply with the requirements of this Act for the transportation of any hazardous waste during site characterization or repository operation and for the transportation of high-level nuclear waste during repository operation.	The DOE projects an ability to comply because all materials will be handled in accordance with DOT regulations regarding the transportation of hazardous and radioactive materials.
Solid Waste Disposal Act, as amended by the Resource Conservation and Recovery Act of 1976 (RCRA) and the Hazardous and Solid Waste Amendments of 1984, 42 USC Sections 6901-6987 (40 CFR Parts 124, 240, 241, and 243-247, 260, 261, 262, 264, 266, 270, 271, 280; E.O. 12088)	This Act contains two major regulatory programs. The Hazardous Waste Program prescribes a system of using manifests, reporting, standards, and permits to achieve controls on hazardous materials from generation to final disposal. These requirements apply to generators and transporters of hazardous waste and owners and operators of hazardous waste storage,	• The DOE must comply with all State, interstate and local requirements relating to the disposal, management, reclamation, recycling, or reuse of solid or hazardous wastes. • The DOE must classify project waste as hazardous or nonhazardous solid waste. • Generators and transporters of hazardous waste must comply with EPA and U.S.	Under provisions in RCRA, Utah was granted final authorization by the EPA to manage its own hazardous and solid waste program, not including the 1984 amendments. All activities associated with hazardous and solid waste management are handled by the Utah Hazardous Wastes Committee. The DOE will consult with the Hazardous Wastes Committee	The DOE projects an ability to comply with this Act based on (1) the type and quantity of waste expected to be generated (Sections 4.1.2.4.6, 4.1.2.6, 5.1.3.5, and 5.4.3.6) (PB/PB-KBB, 1984), and (2) the DOE's plan to use licensed transporters and disposal facilities for any waste that may be generated. (See Utah Solid and Hazardous Waste Act below.)

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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Solid Waste Disposal Act (Continued)	treatment, and disposal facilities, as well as owners of underground storage tanks. The reuse, reclamation, and recycling of hazardous waste also is subject to this regulatory program. The second major program requires each State to prepare a Solid Waste Management Plan to prohibit new open dumps, and can require upgrading or closing of all existing open dumps. Federal guidelines for solid waste collection, transport, separation, recovery, and disposal practices in systems have been promulgated.	Department of Transportation (DOT) manifesting, record keeping, reporting, packaging, labeling, and placarding regulations. • All shipments of hazardous waste are subject to a manifest tracking system. • Until a State program is approved, the DOE must comply with both State and Federal requirements. • Facilities that treat, store, dispose, recycle, reclaim, or reuse hazardous waste must obtain permits. New facilities cannot operate until a permit has been issued by EPA or authorized state agency. • Nonhazardous wastes are regulated under applicable State, local, and regional solid waste plans. • Underground storage tanks are regulated by EPA under the 1984 ammendments.	and the Department of Health in complying with hazardous and solid waste laws. (See Utah Solid and Hazardous Waste Act below.)	
Solid and Hazardous Waste Act, Utah Code Ann. Sections 26-14-1 to 26-14-16; Hazardous Waste Facility Siting Act, Utah Code Ann. Sections 26-14a-1 to 26-14a-9 (Utah Solid Waste Disposal Regulations and Utah Hazardous Waste Management Regulations)	To set forth responsibilities of the Solid and Hazardous Wastes Committee, which has overall responsibility of the State's solid and hazardous waste programs. The Hazardous Waste Facility Siting Act establishes criteria for the siting of new hazardous waste treatment, storage, and disposal facilities. Subject to the powers and rules of the Utah Department of Health, local governments are authorized to supervise and regulate the collection, transportation, and disposi-	• Underground storage tanks are regulated by the EPA under the 1984 Amendments. • Requires approval of hazardous waste operation plan for a facility that will store, treat, or dispose of hazardous waste. The requirements of the State agency parallel those listed above under the Solid Waste Disposal Act, as amended. • Requires compliance with State manifest standards. • The Department of Health may issue an order requiring immediate abatement of a hazardous waste, PCB, dioxin, or asbestos spill.	• The DOE will prepare appropriate manifest documents for any hazardous wastes it generates. • The DOE has made projected classification of wastes expected to be generated by site characterization and repository construction and operation. These wastes are primarily nonhazardous and include: sewage treatment sludge, combustible solids such as paper and cartons, excavated solids including drill cuttings and salts, freshwater and brine drilling fluids (Sections 4.1.2.4.6 and 5.4.3.6). • The DOE has determined that	The DOE projects an ability to comply with this Act based on (1) the type and quantity of waste expected to be generated (Sections 4.2.1.4.6 and 5.4.3.6) (PB/PB-KBB, 1984), and (2) the DOE's plan to use licensed transporters and licensed offsite disposal facilities for any waste that may be generated.

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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Solid and Hazardous Waste Act (Continued)	tion of solid waste within their jurisdictions.	• Requires the development of a State siting plan for hazardous waste disposal facilities. • Seven sites have been identified as existing or proposed sites under the plan. • This Act does not restrict development of sites not included in the plan; it exempts sites included in the plan from compliance with local zoning and land-use ordinances, and limits the liability of owners. • Solid wastes may be disposed of only at a site that has been so designated by the local government and approved by the Department of Health. • No solid waste disposal site may be constructed or operated without the approval of the Department of Health.	licensed disposal facilities for both hazardous and nonhazardous waste are available (Section 4.1.2.4.6). Hazardous waste sites identified under the Hazardous Waste Facility Siting Act will be considered. • The DOE plans to use available landfills for nonhazardous wastes from site characterization. • The DOE will make final decisions regarding disposal of excess salt from the repository later from a number of feasible alternatives (Section 5.1). Disposal of hazardous wastes, if any, will be in a licensed facility that exists at the time the wastes are generated. A currently licensed facility exists west of Salt Lake City, Utah, about 563 kilometers (350 miles) from the site. • If any potentially hazardous waste is actually generated, the DOE will conduct chemical analyses to confirm its composition and support its classification as hazardous or nonhazardous. • DOE will comply with manifest requirements for any hazardous wastes generated. • Expected hazardous wastes are oils and solvents from maintenance operations. These will be stored in drums prior to disposal, recovery, or processing.	

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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Ecology and Wildlife Protection				
Migratory Bird Treaty Act, as amended, 16 USC Sections 703-711 (50 CFR 10.13)	To prohibit killing, capturing, transporting, etc., protected migratory birds, their nests, and their eggs.	Project activities must avoid harm (including indirect effects) to migratory birds, their nests and eggs. Consultations with FWS and State agencies are encouraged.	• The DOE has consulted with the Fish and Wildlife Service (FWS) and will avoid activities at the site being used for breeding and nesting by migratory birds; in this case, raptors (Malone, 1985). Avoidance will be by relocating or rescheduling the activities.	The DOE projects an ability to comply because it will continue to consult with FWS migratory bird specialists concerning locating and mitigating impacts to migratory birds.
Fish and Wildlife Coordination Act, 16 USC Sections 661-666c	To mandate that wildlife conservation receive equal consideration with proposed projects that affect bodies of water.	• Act applies to projects involving the modification, control, or impoundment of a body of water (for impoundments, surface area must be 4 hectares [10 acres] or more). • If these conditions are present, the DOE must consult with State and Federal wildlife agencies to determine measures that prevent, mitigate, or compensate for losses of wildlife resources due to project activities. • The DOE must fully consider reports and recommendations from wildlife agencies, including DOE and State agencies, and include measures that compensate for losses of wildlife resources in project plan.	• The DOE will continue consultation with the Fish and Wildlife Service (FWS) about potential impacts of project activities to fish and wildlife habitat and discuss the need for mitigative measures. • Consultation with FWS indicates that raptors are of major concern, and therefore appropriate mitigation or compensation measures would be incorporated in the project plan and implemented. • The DOE will consult with the State Wildlife Agency regarding potential impacts of subject activities.	The DOE projects an ability to comply because appropriate mitigation measures will be identified and implemented in consultation with FWS and Utah Division of Wildlife Resources. Mitigation measures may include moving planned activities, timing activities to avoid nesting and breeding periods, and controlling project runoff to avoid sedimentation in streams.
Bald and Golden Eagle Protection Act, 16 USC Sections 668-668d (50 CFR Part 22)	To prohibit possessing, killing, transporting, disturbing, etc., bald and golden eagles, their nests, or eggs.	Project activities must avoid negative impacts (including indirect effects) to bald and golden eagles, their nests and eggs. If a golden eagle nest is found and must be moved, the Secretary of Interior may permit relocation of nests if they interfere with resource development or recovery plans.	• Bald eagles occur in the area particularly along the drainages of the Colorado river. No known nesting or roosting areas are located on or near the project area (Cornman, 1983; Radant, 1983). • Golden eagles occur and nest in the project area but nesting habitat is absent on the site (Cornman, 1983;	The DOE projects it can comply with the requirements of this Act because the DOE will implement appropriate mitigative measures, in consultation with FWS and the Utah Division of Wildlife Resources. Mitigation measures may include moving planned activities, timing activities to avoid nesting and breeding periods, etc.

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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Bald and Golden Eagle Protection Act (Continued)			Radant, 1983). Borehole drilling south of Newspaper Rock State Historical Monument will be approximately 1 kilometer (0.6 mile) from a golden eagle nest (Section 4.2.1.2). • The locations of bald and golden eagles will be confirmed during routine biological surveys of all activitiy sites. • The DOE will continue consultation with the Fish and Wildlife Service about appropriate mitigative measures for bald or golden eagles that might be potentially affected by project activities.	
National Wildlife Refuge System Administration Act of 1966, 16 USC Sections 668dd-668ee (50 CFR Parts 25, 27, 28, and 29)	To establish the National Wildlife Refuge System by consolidating authority over fish and wildlife conservation areas under the Secretary of Interior, Fish and Wildlife Service.	Project activities must not conflict with the protection and conservation purposes for which the areas were established.	The Davis Canyon project area is not located on existing or proposed National Wildlife Refuge System land (Young, 1985a). Ouray National Wildlife Refuge is the closest refuge, located approximately 249 kilometers (155 miles) from the site (Young, 1985b).	This statute is not applicable because existing or proposed land within the National Wildlife Refuge System is not close enough to be impacted.
Endangered Species Act of 1973, 16 USC Sections 1531-1543 (50 CFR Sections 17.11, 17.12, 17.94, 17.95, 17.96; 50 CFR Parts 222, 226, 227 402, 424, 450, 451, 452, and 453)	To prohibit Federal agencies from taking any action that would jeopardize the existence of endangered or threatened species or destroy critical habitat.	• The DOE must determine if any listed endangered or threatened species or their habitat will be affected by project activities. • If a listed species or habitat may be affected by the project, the DOE	• The FWS has indicated that the following listed species may occur in the project area: the Colorado squawfish, humpback chub, bonytail chub, American peregrine falcon, bald eagle, and black-footed ferret (Bolwahnn, 1984).	The DOE projects an ability to comply because actions will be taken in consultation with FWS to preserve the continued existence of listed or proposed species. The DOE is committed to meet all regulatory requirements of this act.

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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Endangered Species Act of 1973 (continued)		must provide a written request for consultation to Regional Director, Fish and Wildlife Service (FWS), and follow the FWS procedures. An agency cannot endanger a protected species.	• Six candidate species may occur in the project area (Bolwahnn, 1984). • There are no proposed species or designated critical habitat in the project area (Bolwahnn, 1984). • A site-survey will be conducted in cooperation with FWS endangered species specialist to determine whether such species are present. The need for a biological assessment will then be determined.	
Wild, Free-Roaming Horses and Burros Act, as amended, 16 USC Sections 1331-1340 (43 CFR Part 4700)	To protect all unbranded and unclaimed horses and burros on public lands administered be the BLM and the U.S. Forest Service.	Project activities must avoid harm (including indirect effects) to wild, free-roaming horses and burros on public land.	Wild horses and burros under the jurisdiction of the BLM and the U.S. Forest Service do not occur at the proposed site or in the project area. The closest herd administered by the BLM is the Robbers Roost band located east of Hanksville, Utah. The closest herd administered by the U.S. Forest Service is North Hills located west of Cedar City, Utah (Maxfield, 1985; Sanders, 1985).	This Act is not applicable because protected wild horses and burros do not occur in the project area.
Sikes Act, 16 USC Sections 670a et seq.	To develop conservation and and rehabilitation programs involving the protection and enhancement of wildlife, fish, and game resources on certain federal lands.	The Secretary of the Interior is responsible for developing, with prior approval of DOE, comprehensive plans for conservation and rehabilitation programs to be implemented on DOE land. State agencies may enter into cooperative agreements with DOI and DOE with respect to such conservation and rehabilitation programs.	Although the Act does not impose any requirements directly on DOE, DOE will consult with DOI to determine if a conservation and rehabilitation program is required.	The DOE projects an ability to comply because it will consult with DOI and assist in preparation of any required conservation and rehabilitation plan.

Table 6-3. Environmental Statutory/Regulatory Authorities and Requirements, Davis Canyon
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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/. Actions Planned	Projected Ability to Meet Requirements
Air Quality and Noise				
Noise Control Act of 1972, as amended by the Quiet Communities Act of 1978, 42 USC Sections 4901-4918 (E.O. 12088)	Federal agencies are to carry out their programs in a manner that promotes an environment free of noise that could jeopardize health or welfare.	The DOE is required to comply with Federal, State, interstate, and local requirements for the control and abatement of environmental noise.	• No State, local, or interstate standards have been identified that would be applicable to site characterization or repository construction, operation, or closure (Mongan, 1984). • Consultation with EPA and DOI indicates that audible sounds caused by project activities should be a bases for evaluation of impacts on Canyonlands National Park. • Noise will emanate from equipment and from intermittent, short duration blasting. Equipment noise is not expected to be audible to visitors at Peekaboo Spring, Tower Ruin, Gothic Arch or any other point beyond 2.0 kilometers (1.2 miles) into the eastern portion of Needles District. Blasting noise may be audible up to 24 kilometers (15 miles) from the site under typical conditions. Train noise will be audible within 8 kilometers (5 miles) of the rail line during operation. Noise will be mitigated to below EPA Health and Welfare Guidelines at nearby residences.	The DOE projects an ability to comply because (1) analyses indicate noise levels will be kept below those that would jeopardize health or welfare (Sections 4.2.1.6 and 5.2.7), and (2) equipment noise is audible only along the nearest park boundary, and (3) equipment noise will not be audible at any designated camp area.

Table 6-3. Environmental Statutory/Regulatory Authorities and Requirements, Davis Canyon
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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Clean Air Act, as amended, 42 USC Sections 7401-7642 (40 CFR Parts 50, 51, 52, 58, 60, 61, 124; 40 CFR 81.300 and 81.400) E.O. 12088	To establish air emissions limitations, air-quality standards, and require States to develop a State Implementation Plan (SIP) of strategy for attaining and maintaining air-quality standards. Authority for regulating sources of air emissions in Utah has been delegated to the State by the Federal EPA.	• The DOE is required to comply with all Federal, interstate, State, and local requirements relating to the control and abatement of air pollution. • Sources of air pollution must comply with emissions standards and other requirements. In addition, air pollutant emissions must not cause national ambient air quality standards (NAAQS) to be exceeded. If the emission rate of any criteria air pollutant from a stationary source is greater than 227 metric tons (250 tons) per year, the project must undergo prevention of significant deterioration (PSD) review.	• Since Utah has been delegated authority to administer the Clean Air Act (42 USC Sections 7401-7642), compliance with Utah law will satisfy Federal Clean Air Act requirements.	• See Utah Air Conservation Act.
Air Conservation Act, Utah Code Ann. Sections 26-13-1 to 26-13-30 (Utah Air Conservation Regulations)	To establish a Statewide program of air pollution prevention, abatement and control in order to achieve and maintain levels of air quality that protect health, safety, and the environment.	• The proposed installation must be in accord with applicable requirements of National Standards of New Source Performance Standards (NSPS), National Primary and Secondary Air Quality Standards (NAAQS), National Emission Standards for Hazardous Air Pollutants (NESHAPS), and Utah Air Conservation Regulations, including visible emissions limitations, and mandatory fugitive emissions and fugitive dust control techniques. • Prior to the construction of any sources of air pollution, the DOE must obtain an approval order from the Utah Air Conservation Committee Executive Secretary.	• Emission inventory of criteria pollutants has been established for site characterization and repository construction and operation. Stationary source emissions are below the levels which trigger PSD requirements (227 metric tons [250 tons] per year). This does not include construction-related fugitive emissions, which not counted in the PSD major source determination. The steam plant is the only source that is regulated by NSPS. However, the steam plant which has a 124 million Btu per hour capacity, is below the minimum size (250 million Btu per hour) necessary to trigger NSPS requirements) or the 100-ton PSD major source threshold.	• The DOE projects an ability to comply because the DOE has projected (1) no significant impairment to visibility, (2) no impacts to soil or vegetation due to air-pollutants, (3) odorous emissions will be limited to diesel emissions near the site, and (4) night sky glow during repository operations can be mitigated to existing background levels (Sections 4.4.1, and 5.5.1). • In addition, the DOE has projected that it will be able to meet all other applicable requirements including the requirement that it utilize best available control technologies (BACT) for all sources of air pollution.

Table 6-3. Environmental Statutory/Regulatory Authorities and Requirements, Davis Canyon
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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Air Conservation Act (Continued)		• Utah Air Conservation Regulations require that pollutant control for emissions be at least best available control technology (BACT). • Utah provides for review by the Federal Land Managers (FLM) of Federal lands. The FLMs of Class I areas determine whether air quality-related values (AQRVs) in the Class I area would be adversely affected.	• Other than fugitive particulate emissions, the only significant emissions are oxides of nitrogen (NO_x). During site characterization borehole drilling rigs and drivers for electric generators will emit under 227 metric tons (250 tons) per year of NO_x in the peak year (Section 4.2.1.3). The steam plant for the repository will emit 91 metric tons (100 tons) per year of NO_x (Section 5.2.5). Preliminary air quality estimates show TSP and NO_x concentrations during all phases of characterization and repository construction, operation, and closure would be below NAAQS. • No sources of hazardous air pollutants are known, therefore, NESHAPS requirements are not triggered. • Site characterization and repository engineering designs include plans for BACT on stationary sources and controls on fugitive dust emissions. Use of BACT controls will ensure compliance with any applicable visible emission requirements. • Air quality concentrations inside the Class I area of Canyonlands National Park have been estimated, with emissions from fugitive and mobile sources included among the sources of total suspended particulates (TSP). Maximum concentrations are projected to occur during the 1 year of site preparation	

Table 6-3. Environmental Statutory/Regulatory Authorities and Requirements, Davis Canyon
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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Air Conservation Act (Continued)			for the repository. During this time, maximum 24-hour TSP concentrations at the boundary of the park may reach up to 62 micrograms per cubic meter and are due largely to fugitive emissions from earthmoving equipment. The annual average NO_x concentration at the boundary of the park will be approximately 21 micrograms per cubic meter throughout the construction period. Concentrations decrease rapidly with distance into the park. Results of an EPA level-2 visibility analysis indicate that projected visibility changes are expected to be imperceptible within the park during all phases of site characterization and repository construction and operation. The visibility analyses utilize standard EPA visibility methodologies and find no perceptibility impairments. The DOE will consult with the National Park Service (NPS) and the State of Utah to determine whether unusual conditions not examined by these methodologies need to be addressed. • Preliminary meetings have been held with the NPS, BLM, EPA Region VIII, and the Utah Division of Environmental Health, to determine their requirements and directions. • Further air-quality modeling is planned when onsite meteorological data are obtained.	

Table 6-3. Environmental Statutory/Regulatory Authorities and Requirements, Davis Canyon
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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Cultural Resources				
Archaeological Resources Protection Act of 1979, 16 USC Sections 470aa-47011 (36 CFR Part 296; 43 CFR Part 7)	To protect archaeological resources located on United States public lands (includes most Federal land) or Indian lands.	• The DOE must determine if archaeological resources that may be damaged during project-related activities are present on Federal land. • Assessment and consultations with the SHPO are required if resources are discovered. • If excavation and removal become necessary, the Federal Land Manager having jurisdiction over the land must give permission.	• The DOE has conducted surveys of over 8,094 hectares (20,000 acres) in the project area. Of the archaeological resources found, some are believed to be eligible for National Register listing. While additional surveys may reveal other sites, none found are in the restricted area, where most construction will occur (Section 3.4.6).	The DOE projects an ability to comply because the DOE is committed to avoid archeological resources. Removal of resources will be done in accordance with the future PMOA.
National Historic Preservation Act of 1966, as amended, 16 USC Sections 470-470w-6 (36 CFR Parts 60 and 800; E.O. 11593 Historic Sites, Buildings and Antiquities Act, 16 USC Sections 461-467; Archaeological and Historic Preservation Act, 16 USC Sections 469-469c. (36 CFR Parts 62, 63, 65, and 296; 43 CFR Part 7)	To protect districts, sites, buildings, structures, and objects significant in American history, architecture, archaeology, and culture that are included in or eligible for inclusion in the National Register.	The DOE must request information from the SHPO and study existing literature to determine whether or not project area contains any structure or object listed in or eligible for inclusion in the National Register. If resources are known to be in the area, or if requested by the SHPO, the DOE should survey the site to identify resources. If project area contains resources that are eligible for inclusion in the National Register, the DOE must determine the effect that any project activities may have on the resource. If effect would be adverse, the DOE must prepare a plan of mitigation and con- with the Advisory Council on Historic Preservation.	• The DOE has conducted surveys of over 8,094 hectares (20,000 acres) in the project area. The DOE is currently consulting with the BLM and the Utah SHPO as to which of the identified archaeological sites would be eligible for listing in the National Register, and what the precise impacts to resources may be. Several of the identified sites will require archaeological testing before the SHPO and keeper of the National Register can make a formal determination of eligibility (Sections 4.2 and 5.2). • Should the site be selected for site characterization, the DOE will consult with the SHPO regarding the need for additional archaeological studies and eligibility of any resources identified. For site characterization, a Programmatic Memorandum of Agreement (PMOA) among the DOE, the BLM, the	The DOE projects an ability to comply because it is proceeding with appropriate procedural steps as set out in the Act. Based on consultations with the BLM, the SHPO, and the Advisory Council Historic Preservation, and as specified in the PMOA the DOE will continue to conduct archaeological surveys, determine elgibility or archaeological sites, and develop mitigation plans.

Table 6-3. Environmental Statutory/Regulatory Authorities and Requirements, Davis Canyon
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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
National Historic Preservation Act (Continued)			Advisory Council on Historic Preservation (ACHP), and the State Historic Preservation Officer will be executed (DOE, 1985).	
American Antiquities Act, 16 USC Sections 432 and 433 (25 CFR Part 261; 36 CFR Part 296; 43 CFR Part 3 and 7)	Act protects historic and prehistoric ruins, monuments, and objects of antiquity located on the lands owned or controlled by the Federal government.	• If historic or prehistoric ruins or objects of antiquity are found on Federal land, the DOE must determine if project will adversely affect resources. • Secretary of the DOI or the DOA will have to grant permission to proceed before activities may be undertaken that could result in appropriation, excavation, injury, or destruction to any historic ruin or antiquity.	• The DOE has conducted surveys of the project area and found ruins or objects of antiquities (Sections 4.2 and 5.2). • The DOE will seek a formal determination from BLM of effects on identified resources located on BLM land. • During site characterization and repository construction, the DOE would perform assessment of potential impact on any resources identified and take appropriate resources to avoid such measures, or institute a data recovery program.	The DOE projects an ability to comply because the DOE is committed to institute a data recovery program for any resources discovered in accordance with this Act and the PMOA if the resource may be affected during site characterization or repository construction activities.
American Indian Religious Freedom Act of 1978, 42 USC Section 1996 (36 CFR Part 296; 43 CFR Part 7)	Act protects and preserves Native American religions and practice.	• The DOE must determine if project area is in an area related to Native American religious rites or is a sacred site of any Native American group. • If the site is in such an area, the DOE should consult Native American leaders to determine if project would infringe on religious practices. If infringement is possible, the DOE should consider alternatives. If no feasible alternative is available, project must be reviewed by Office of Intergovernmental Affairs, and approved by the Secretary of Energy.	• The Bureau of Indian Affairs has informed the DOE that no federally recognized Native American Tribes are located in San Juan County (Oxendine, 1984). • The DOE will conduct further consultations with appropriate tribal leaders when they are identified. If infringement on religious practice appears possible, the DOE will consider alternatives and consult with the Office of Intergovernmental Affairs.	The DOE projects an ability to comply with requirements of this Act because the DOE will complete required contacts and consider alternatives, if the site is in an area related to Native American religious rites or if the site is in a sacred area of any Native American group.

Table 6-3. Environmental Statutory/Regulatory Authorities and Requirements, Davis Canyon
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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Hydrology and Water Quality				
Federal Water Pollution Control Act, as amended by the Clean Water Act of 1977, 33 USC Sections 1251-1376 (40 CFR Parts 110, 116, 117, 121, 122, 123, 124, 125, 129, 230, 401, 403; 33 CFR Parts 209, 320, 323-327, 330) (E.O. 12088)	Act regulates pollution of the waters of the United States.	• The DOE must obtain a National Pollutant Discharge Elimination System (NPDES) Permit from the Federal EPA for discharges from sediment retention basins and sewage treatment facilities planned for the ESF and any discharges to waters of the United States, from the repository. • The DOE must comply with Section 404 dredge and fill permit regulations. • Subject to certain conditions, activities such as core sampling, seismic exploratory operations, and plugging of seismic shot holes, may be conducted under nationwide permits. In addition, under the nationwide permit system and subject to certain conditions, only notification of the District Engineer is required when waters (including wetlands) of less than 4 hectares (10 acres) are affected. Impacts to wetlands greater than 4 hectares (10 acres) would require a permit from the COE. • The DOE must obtain a water quality certification from the State of Utah.	The DOE will complete and submit NPDES permit and Section 404 dredge and fill permit applications as required. Final engineering design will be provided prior to submission of permit applications.	The DOE projects it can meet Federal and State water pollution control requirements because discharges will be minimal (Sections 4.2.1.4 and 5.2.2.1); engineering control measures will be applied to keep discharges within allowable limits and such review will be applied to meet any applicable Section 404 dredge and fill permit requirements as described in Sections 4.1.2.2 and 5.1.2.3.
Utah Water Pollution Control Act, Utah Code Ann. Sections 26-11-1 to 26-11-20 and 26-15-4 (Utah Wastewater Disposal Regulations)	To establish a Statewide program of water pollution prevention, control, and abatement in order to achieve and maintain levels of water quality which protect health, safety, and the environment.	• The permit for discharge of a pollutant into waters of the State must be approved by Utah Water Pollution Control Committee "Waters of the State" include all bodies of water within	The DOE will complete and submit permit applications.	The DOE projects an ability to comply for reasons outlined above (Clean Water Act of 1977) (33 USC Sections 1251-1376).

Table 6-3. Environmental Statutory/Regulatory Authorities and Requirements, Davis Canyon
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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Utah Water Pollution Control Act (Contined)		the State except those confined to and retained within the limits of private property and which do not constitute a nuisance. Effluent limitation standards under the permit cannot be more stringent than those standards provided in Utah Code Ann. Section 26-11-5.5. Water quality standards for permit are provided in Wastewater Disposal Regulations, Utah Water Quality standards, Utah State Division of Health, Part II and include the Colorado River Salinity Standards pursuant to Part II, Section 2.4. • Any persons who spill or discharge any oil or other substance that may cause the pollution of the waters of the State shall immediately notify the Executive Secretary of the Utah Water Pollution Control Committee of the spill, containment procedures, and proposed procedure for cleanup and disposal.		
Rivers and Harbors Appropriation Act of 1899, 33 USC Sections 401-413 (33 CFR Parts 209, 320,322,325,326, 329,330) Bridge Act of 1906, 33 USC Section 491 et seq.	To prevent any alteration or modification of the course location, conditions or capacity of any channel of any navigable water of the United States without a permit. Construction of bridges is also regulated.	• A permit is required from the Coast Guard for the construction of bridges over any navigable water. Obstruction of a navigable water is prohibited without a permit from the U.S. Army Corps of Engineers (COE). • The DOE must obtain a permit from the COE if fill	• The reference railroad route crosses the Colorado River just north of the San Juan/ Grand County line. Such crossings along with other drainage crossings will affect navigable waterways under COE jurisdiction (Section 5.1.2.2). The DOE will initiate permitting	The DOE projects an ability to comply because it will meet COE and Coast Guard regulations and because there is flexibility in designing and constructing the required river and stream crossings.

Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
General Bridge Act of 1946 33 USC Section 525 et seq. (33 CFR Parts 114 and 115)		material is put into navigable waters.	procedures with the COE as appropriate and Safe Drinking Water Act of Utah below for public drinking water system compliance information. • The DOE will consult with the U.S. Coast Guard (CG) to determine applicability of Act to plans for the construction of a bridge across the Colorado River and to determine Grand County's (CG's) jurisdiction over bridge construction.	
Safe Drinking Water Act, 42 USC Sections 300f-300j-10 (40 CFR Parts 122, 124, 141, 142, 143, 144, 145, 146, 147) E.O. 12088	To regulate public water supply systems and to prevent pollution of underground sources of drinking water.	• The DOE must comply with all Federal, State and local requirements regarding drinking water if public water system is proposed. • The DOE must obtain an underground injection control permit or use a licensed underground injection well facility, if underground injection is chosen as method of disposal for brine or, if other activities involve injection. • Utah Division of Environmental Health is granted authority to issue UIC permits for Class I, III, IV, and V, and to regulate safe drinking water programs. Compliance with State law satisfies the Federal Safe Drinking Water Act (42 USC Sections 300f-300j-10). • Federal agencies are prevented from granting assistance to any project that may contaminate an EPA-designated sole source aquifer so as to create a significant health hazard.	• See Utah Water Pollution Control Act below for underground injection control (UIC) compliance information and Safe Drinking Water Act of Utah below for public drinking water system compliance information. • No EPA-designated sole source aquifers are located near the site.	• See Utah Water Pollution Control Act and Safe Drinking Water Act.

Table 6-3. Environmental Statutory/Regulatory Authorities and Requirements, Davis Canyon
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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Utah Water Pollution Control Act, Utah Code Ann. Sections 26-11-1 to 26-11-20	To create the Utah Water Pollution Control Committee, which has responsibility for regulating and permitting underground injections.	• An underground injection control permit must be obtained for any subsurface emplacement of fluids. Under authority of Utah Code Ann. Sections 26-11-1 to 26-11-20 (1984), and Wastewater Disposal Regulations, Part VII (Underground Injection Control Program) (May 2, 1985), as authorized by the Safe Drinking Water Act (42 USC Section 300h [1980]) and 40 CFR Parts 122, 123, 124 and 146 (1984), Permits for Class I, III, IV, and V underground injection wells are approved and regulated by the Utah Water Pollution Control Committee.	• Disposal of waste salt by brine injection is not a viable option due to the large volume of water required. • Consultation with the Division of Environmental Health will determine if other activities (e.g., well testing) will require a permit for a Class V well.	• The DOE projects an ability to comply since underground injection is not planned for salt disposal and since the DOE will comply with permit requirements for Class V wells if this permit is necessary.
Safe Drinking Water Act of Utah, Utah Code Ann. Sections 26-12-1 to 26-12-12 (Public Drinking Water Regulations, April 16, 1984)	To regulate development of public drinking water systems.	This Act requires that the Executive Secretary of the Safe Drinking Water Committee must approve all plans and specifications for public drinking water projects, which includes a system that provides water for 15 service connections or at least 25 persons daily, even though privately owned.	The DOE will secure approval from the Utah Safe Drinking Water Committee for any drinking water system proposed on site.	The DOE projects an ability to comply as it will comply with the permit requirements of Utah, and ensure that any water system which falls within the definition of a public drinking water system is designed to meet Utah specifications.

Table 6-4. Non-Federally-Derived State and Local Statutory and Regulatory Authorities, Davis Canyon Site

STATE REQUIREMENTS
Land Use
Resource Development Coordinating Committee Act, Utah Code Ann. Sections 63-28a-1 et seq. (Guidelines for Implementation of the Resource Development Coordinating Committee Act, 1981)
Materials Permit, Utah Code Ann. Section 65-1-15(4) (Rule M1b1, Rules and Regulations Governing the Issuance of Mineral Leases)
Parks and Recreation, Utah Code Ann. Sections 63-11-1 to 21
Forestry, Utah Const. Article XVIII, I; Utah Code Ann. Sections 24-2-3(3) and 12
Utah Mined Land Reclamation Act, Utah Code Ann. Sections 40-8-1 et seq. (General Rules and Regulations)
Special Use Lease of State Lands, see Utah Code Ann. Section 65-1-108, Rules and Regulations Governing the Issuance of Special Use Leases
Rights-of-Way Across State Lands, Utah Code Ann. Section 65-2-1 et seq., Rules and Regulations Governing the Issuance of Rights of Way and Rights of Entry.
Ecology and Wildlife Protection
Wildlife Resources Code of Utah and other Acts that Protect Wildlife Resources, Utah Code Ann. Sections 23-13-1 et seq., 23-14-1 et seq., 23-15-1 et seq., 23-17-1 et seq., 23-18-1 et seq., 23-21-1 et seq.
Heritage Tree Protection, Utah Code Ann. Sections 63-11-57 to 63-11-65
Cultural Resources
State History Act, Utah Code Ann. Sections 63-11-2 and 63-18-25

Table 6-4. Non-Federally-Derived State and Local Statutory and Regulatory Authorities, Davis Canyon Site
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Hydrology and Water Quality
License for Well Drillers, Utah Code Ann. Section 73-3-25 (Utah Admin. Rules for Water Well Drillers, July 1, 1985)
Application to Alter Natural Stream, see Water and Irrigation, Relocation of Natural Streams, Utah Code Ann. Section 73-3-29
Transportation
Utah Code Ann. Section 41-6-154

Table 6-5. Measures to Control Potential Adverse Environmental Impacts - Davis Canyon

Potentially Significant Adverse Environmental Impacts	Control Measures to be Employed	Projected Effectiveness of Control Measures	Acceptability of Residual Impacts
Water Quality:			
Surface Water			
Minor and temporary increases in sediment and turbidity in Indian Creek during siting activities (Section 4.2.1.4.1).	Construction of temporary sediment basins during siting and construction (Sections 4.1 and 5.1). Water spraying and salt and spoils pile management to control dust and salt during construction and operation (Section 4.2.1.12). Salt and spoils pile catch basins to prevent contaminant release during operation.	Design criteria for runoff control structures should prevent release of contaminants. Control measures are expected to reduce windblown dust by at least 90 percent, reducing contamination of water by airborne particulates.	The DOE expects residual impacts to be acceptable because they will be limited to local and temporary increases in sediment loads prior to completion of sediment ponds, and to windblown solids which will have an imperceptible impact on water quality in streams or in the Colorado River.
Ground water			
Contamination of ground water as a result of hydraulic connection of aquifers, wastewater seepage from salt pile and evaporation ponds during siting, construction, and operation as well as mud pits during siting and construction (Sections 4.2.1.4.2, 5.2.2.2.1, and 5.2.2.2.2).	Use of water seals, collars, and shaft liners to vertically isolate aquifers and use of appropriate drilling mud to minimize contamination. Use of liners in the mud pits, under salt piles, and in evaporation ponds to prevent leakage. Monitoring and recovery system will be installed to detect and pump out leakage.	Control measures should substantially reduce the probability and extent of any ground-water contamination, if any. The DOE will rely upon early detection and clean up if liner leakage develops.	The DOE expects residual impacts to be acceptable because the potential volume of contaminated ground water will be small relative to the aquifer volume due to efficacy of the control measures, early detection by the monitoring system, and quick remedial action.
Air Quality:			
Increased suspended particulate and gaseous emissions during siting, construction, and operation leading to increased concentrations of air contaminants. Reduction in visibility from increased concentrations of air pollutants (Sections 4.2.1.3 and 5.2.5). Projected increases in TSP concentrations are based on fugitive dust emission factors, which are assumed to be suitable for modeling TSP impacts (Section 5.2.5.3.2). These factors were developed from offsite measurements where soil characteristics such as silt and moisture content may differ from those existing at the site.	Water spraying, soil stabilization, salt and spoils pile management measures to reduce airborne particulates. Paving and cleaning of site access roads. Vehicle traffic restrictions and speed limits.	Water spraying and soil stablization are projected to reduce emissions of airborne dust by at least 90 percent. Perceptible increases in suspended particulates and dustfall will be confined to the canyon in the immediate vicinity of the site.	The DOE believes that residual air quality impacts at the site boundary are acceptable because they are less than applicable permitting levels, the clarity of the air is not impaired, and there are no perceptible impacts to the other Canyonlands National Park air quality-related values except for night skyglow which may be perceptible during site characterization and repository construction.

Table 6-5. Measures to Control Potential Adverse Environmental Impacts - Davis Canyon
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Potentially Significant Adverse Environmental Impacts	Control Measures to be Employed	Projected Effectiveness of Control Measures	Acceptability of Residual Impacts
Cultural Resources:			
Direct impacts during siting and construction, and indirect impacts during siting, construction, and operation on sites eligible for the National Register of Historic Places (Sections 4.2.1.8 and 5.2.8).	Mitigation plans will be developed in consultation with the State Historic Preservation Officer (SHPO), Bureau of Land Management (BLM), and Advisory Council on Historic Preservation (ACHP). Sites will be avoided by relocating activities whenever possible. Important sites which cannot be avoided will be recovered. Project personnel will receive worker awareness training regarding the sensitivity of cultural resource sites. (Sections 4.2.1.8 and 5.2.8).	Mitigation plans should control all direct site and corridor impacts. Minor indirect impacts are projected to occur in relation to changes in visitation (Sections 4.2.1.8 and 5.2.8).	The DOE believes that residual impacts are acceptable because direct impacts can be controlled or eliminated and the indirect impacts can be mitigated.
Soils:			
Soil contamination by windblown salt or leakage from retention ponds during construction (5.2.1.1.1) and operation (5.2.1.1.2). Subsoil horizons mixing in stripped topsoil during siting (4.2.1.5.1) and construction (5.2.1.1.1). Paving and removal of vegetation may increase surface runoff, and thus increase soil erosion. Wind erosion of soils stripped of vegetation during site characterization (4.2.1.5.1) and repository construction.	Retention pond liners with leakage detection and recovery system, and salt pile management measures. Nutrients and soil conditioners where necessary to support vegetative growth when stripped topsoil is stabilized or redistributed. Soil banking, ridging and diking, indigenous natural vegetation seed sprays, runoff diversion structures and retention ponds will be used. Water spraying, soil stabilization, and revegetation to reduce wind erosion of exposed soils.	Pond liners are projected to reduce the potential for soil contamination. Leakage is beyond the double liner system, and expected to be infrequent. Salt management measures are expected to eliminate soil contamination except in the immediate vicinity of the salt pile and transfer points. Runoff control measures will retard increased surface runoff and prevent increases in soil erosion by surface water. Water sprays are projected to reduce airborne particulate emissions by at least 90 percent in areas of exposed soil. Revegetation measures should reduce wind erosion to approximately the undisturbed levels in revegetated areas.	The DOE believes that soil contamination and soil erosion impacts can be held to acceptable levels because effective engineering control measures (liners, soil stablization, revegetation) are planned to reduce these impacts.
Noise:			
(Schultz, 1978 and Section 5.2.7). During construction, noise levels will be audible up to 2.4 kilometers (1.5 miles) into Canyonlands Park (Section 4.4.1.3). Noise levels from blasting will be audible up to 24 kilometers (15 miles into Canyonlands National Park (Section 4.4.1.3). Increased noise levels from construction of rail and road access routes will result in	Near surface shaft and tunnel blasting will occur only between 0700 and 2200 hours. Calculations have taken account of the DOE's ability to select quiet equipment, use noise muffling devices, enclose stationary noise producing equipment, and use sound absorbing materials.	Feasibility of enclosing major noise producing equipment has been established (BNI, 1985).	The DOE believes the noise impacts to be generally acceptable because noise in well-travelled areas will be limited to blasting noise audible only for short durations for exploratory shaft, repository shaft, and railroad construction (4.2.1.6 and 5.2.7). Long term audible levels of equipment noise are not expected to be present at often visited places.

Table 6-5. Measures to Control Potential Adverse Environmental Impacts - Davis Canyon
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Potentially Significant Adverse Environmental Impacts	Control Measures to be Employed	Projected Effectiveness of Control Measures	Acceptability of Residual Impacts
Noise: (Continued)			
increased noise levels at Dugout Ranch, Indian Creek State Park, northern Bridger Jack WSA, and Needles Overlook. Equipment noise levels will be audible 12 kilometers (7.5 miles) into Canyonlands National Park during repository operation. Predicted L_{dn} levels at Dugout Ranch are below recommended EPA guidelines. Sound emission levels used in the analysis are believed to be accurate to $\pm$ 5 dB. Unfavorable wind and temperature gradient effects, which would increase noise propagation toward the park, are believed to be an infrequent occurrence.			Opportunities for solitude in the proposed Wilderness Area at the eastern park boundary may be impacted by increased noise levels. The increases will be much less than that from commercial airline overflights which occur daily every 2 to 3 hours and last for 2 to 3 minutes.
Visual Aesthetics:			
The ESF is potentially visible from four key observation points, and a total area of 71.33 square kilometers (27.54 square miles). Significant impacts may occur as the facility is viewed from the Davis Canyon jeep trail and Utah 211. Tall structures at the site will be visible from limited areas within Canyonlands National Park, although few visitors will be affected due to low visitation in these areas (Sections 4.2.1.7 and 5.2.6). No key observation points within Canyonlands National park will be impacted because the facilities are not visible. Rail access routes, and especially cuts and fills, will be visible from some key overlooks during construction and operation. Night lighting and navigation warning lights may degrade visual character of the night sky during siting (Section 4.2.1.3), construction, and operation (Section 5.2.5).	Control measures will include orienting and painting structures to blend with the surroundings, tinting exposed concrete surfaces, and use of directional and infrared security lighting. Cut and fill slope edges and boundaries of construction clearings will be planned to reduce their contrast with the natural surroundings. Revegetation, tunnels, berms, and route relocation will be used to mitigate visual impacts of rail access routes (Section 5.2.6).	Control measures are projected to reduce visual contrast and obtrusiveness of structures and transport routes, as well as skyglow during nighttime hours. Portions of the railroad will remain visible from scenic overlooks along the routes considered in Section 5.2.6. Markers and earthmounds erected after decommissioning will be designed to be compatible with natural surroundings (Section 5.2.6).	The DOE believes that most visual aesthetic impacts can be mitigated to an acceptable degree because (1) the repository and support facilities will not be visible from generally travelled parts of Canyonlands National Park (Section 5.6.1) and (2) portions of the alternative railroad alignment will be in the line of sight of some area view points and have high visual contrast for some segments. Night skyglow may be perceptible during construction but will not significantly reduce star visibility.

Table 6-5. Measures to Control Potential Adverse Environmental Impacts - Davis Canyon
(Page 4 of 4)

Potentially Significant Adverse Environmental Impacts	Control Measures to be Employed	Projected Effectiveness of Control Measures	Acceptability of Residual Impacts
Biota:			
Loss of plant communities and mortality of small sedentary wildlife from siting and construction. Increased road kills during siting, construction, and operation. Loss or change in plant communities adjacent to site due to salt deposition during siting, construction, and operation. Transportation routes creating a potential behavioral barrier to some wildlife (Sections 4.2.1.2 and 5.2.4).	Minimize clearing, grubbing, and grading activities. Erect cattle guards and fences to prevent wildlife access to the repository operations areas. Salt management procedures and control structures to reduce salt deposition. Sites restored in conformance with BLM specifications. Transportation routes and utility corridors will be designed to reduce impacts on wildlife.	Control measures should limit impacts to biota except for localized destruction or displacement. Transportation route selection and design should reduce impact on behavior, and reproduction of sensitive biota.	The DOE expects adverse impacts to be acceptable because they will be localized, and limited to ecosystems which are not unique, critical, or sensitive, and are not expected to affect threatened or endangered species in the site area and only temporarily in the Colorado River. (Sections 4.2.1.2, 5.2.4.1, 5.2.4.2, and 5.2.4.3).
Land Use:			
Removal of 2,331 hectares (5,760 acres) from the jurisdiction of the public land laws (Sections 4.1.3.3 and 4.2.1.1) and extinguishing of existing mineral rights and oil and gas leases. Temporary disturbance of existing grazing activities on 59 hectares (145 acres) during site characterization field activities and a temporary change in the recreational experience in the vicinity of the activities (Section 4.2.1.1). Loss of 162 hectares (400 acres) of grazing land and a change in the recreational experience during repository construction and operation. Development of mineral resources within the controlled area will be prohibited. (Sections 4.2.1.1 and 5.2.3.1).	Restoration of grazing land in accordance with BLM specifications upon completion of activities. Provide cattle crossings where necessary along transportation corridors.	Control measures are expected to reduce impacts to grazing, and other land-use interests.	The DOE expects impacts to grazing to be insignificant since the disturbance will represent only a small portion of the range inventory in BLM Moab grazing district (5.2.3). The DOE also expects impacts to recreation to be acceptable because access through Davis Canyon will be maintained for hikers and four-wheel drive vehicles. The presence of industrial development (the repository) would be perceptible along Utah 211, the access road to the park.
Salt Management and Disposal:			
Windblown salt, salt seepage into ground water, decrease in soil and vegetation productivity.	Collection and evaporation of salt pile runoff. Reduction of salt emissions and windblown salt via enclosed salt handling and pile crusting. Liners and leachate monitoring of salt ponds and storage areas.	Control measures are expected to reduce salt impacts to insignificant levels.	No significant offsite impacts because increases from the project will probably not be detectable.

Note: References are to sections in the EA where potential adverse impacts, control measures and their effectiveness, and residual impacts are discussed.

6.2.1.6.2 Analysis of Favorable Conditions

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

Evaluation. The DOE has identified the Federal and federally delegated environmental statutory and regulatory requirements potentially applicable to the Davis Canyon site. Table 6-3 lists the requirements, the compliance demonstrated, the actions planned, and the projected ability to meet the requirement at the Davis Canyon site based on available information and analysis.

The DOE projects the ability to meet environmental requirements potentially applicable to the site and the activities proposed to take place thereon and adjacent to the project area (Table 6-3).

The project area referred to in Table 6-3 refers to the project site and also encompasses project activities located off site (e.g., geotechnical activities, support facilities, access routes, and utility corridors).

However, the DOE cannot project ability to meet all such requirements within time constraints due to the uncertainty in the time required to obtain all permits and approvals, including the Utah Air Conservation approval order.

The DOE intends to comply with all State and local environmental requirements, as listed in Table 6-4, not inconsistent with its responsibilities under the NWPA. The DOE intends to consult with State and local officials concerning sites that are recommended to determine the scope of requirements and to identify other regulations as appropriate.

The evidence indicates that the favorable condition is not present.

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

Evaluation. Potentially significant adverse environmental impacts, control measures and their effectiveness at reducing these impacts, and the acceptability of the residual impacts are presented in Table 6-5. As summarized in Table 6-5, effective control measures are available to substantially reduce all potentially adverse impacts to acceptable levels for site characterization or repository construction and operation. However, some of the impacts cannot be mitigated "to an insignificant level through the application of reasonable measures, taking into account programmatic, technical, social, economic, and environmental factors."

For example, noise from blasting will be temporary and intermittent and it can be limited to certain hours of the day, but it cannot be mitigated to become inaudible (Sections 4.2.1.6 and 5.2.7). Similarly, there will be access corridors and repository facilities visible from the park such that visual effects will occur (see Sections 4.4.1, 5.5.1). Following decommissioning of a nuclear waste repository in less than 100 years, no significant environmental impacts to future generations at the project area or the Canyonlands National Park have been identified. The markers of the repository area will be designed to be compatible with the park values. However, a favorable condition is not present because all interim impacts cannot be mitigated to an insignificant level.

The evidence indicates that the favorable condition is not present.

6.2.1.6.3 Analysis of Potentially Adverse Conditions

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

Evaluation. Based on the information presented in Tables 6-3 and 6-4, the DOE does not project a major conflict with applicable Federal, State, and local environmental requirements

Because the DOE believes there will be no substantial adverse impacts on air quality-related values in the Canyonlands National Park (Table 6-5), and because there is considerable flexibility regarding the location and design of the water intake structure in, and the railroad bridge across, the Colorado River, no major conflict with applicable Federal environmental regulations is found.

The DOE has identified State environmental requirements as listed in Table 6-4. The DOE intends to comply with the requirements of applicable State and local laws and regulations, but has based its findings for this guideline on those statutes listed in Table 6-3.

A potentially adverse condition is not present, because no major conflict with applicable Federal or State environmental requirements is projected.

The evidence indicates that the potentially adverse condition is not present.

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

Evaluation. Potentially significant adverse environmental impacts and the control measures used to reduce these impacts are outlined in Table 6-5. Table 6-5 reflects that there are projected significant adverse environmental impacts related to air quality and noise levels within Canyonlands National Park, and noise levels, visual contrast, and industrial presence outside the park. As indicated in the columns headed "Projected Effectiveness of Control Measures" and "Projected Acceptability of Residual Impacts" in Table 6-5 the control measures to be employed to mitigate environmental impacts are as follows:

1. Engineering control measures will reduce water quality impacts, to minor, local, or temporary effects.

2. Air pollutant emission controls will reduce emissions to the point where only minimal changes in local air quality are expected; however, because the air quality in Canyonlands National Park will be affected, these changes are considered to be significant.

3. Direct impacts on cultural resources can be controlled or eliminated, and indirect impacts reduced (through the use of worker awareness programs) to the level where no significant loss of cultural resource information is expected.

4. Soil contamination and erosion can be reduced to low levels by the use of pond liners, soil stabilization, and revegetation.

5. Noise control measures have been applied; some further reduction in noise impacts may be achievable with additional control measures.

6. Facility and access corridor placement and design can reduce visual impact to the point where the repository and support facilities will not be visible from most parts of Canyonlands National Park. Control measures will be employed to reduce the visual intrusiveness of night lighting during site characterization and construction. All four alternative access routes represent a significant visual impact from one or more key observation points outside the park.

7. Facility and access corridor placement and design can reduce impacts on biota to the point where they will be localized; limited to ecosystems which are not unique, critical, or sensitive; and do not adversely affect threatened and endangered species in the site area and temporarily in the Colorado River.

8. Restoration of grazing land, provision of cattle crossings, and reducing noise and visual impacts will reduce land-use impacts to the point where only a small portion of the land available for grazing or recreation will be affected.

The air quality in Canyonlands National Park will be degraded. The DOE is projecting peak TSP and NO_x levels at the park boundary to be 62 and 22 micrograms per cubic meter respectively, which represents increases over background levels. All other projected significant adverse environmental impacts can be mitigated through the use of control measures.

The evidence indicates that the potentially adverse condition is present.

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

Evaluation. The geologic repository operations area (GROA) lies within 1.6 kilometers (1 mile) of the eastern boundary of Canyonlands National Park. TSP and NO_x concentrations within the Canyonlands National Park boundary are projected to increase. However, results from EPA's visibility methodologies show visibility changes to be imperceptible within the park. The repository will be visible during daylight hours at some places along the eastern boundary of Canyonlands National Park, however, this is not a heavily visited part of the park. Night lighting may perceptibly increase night sky glow during site characterization and repository construction. Blasting, during site characterization and construction activities, will be audible within the park. Discussions of the extent of these and other impacts during repository siting, construction, and operation are presented in Sections 4.2.1.12 and 5.2.11 and lead to the conclusion that (with the exception of air quality and noise degradation) no significant adverse environmental impacts from the repository or its support facilities are projected on Canyonlands National Park.

The evidence indicates that the potentially adverse condition is present.

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

Evaluation. The nearest such protected resource is Newspaper Rock State Historical Monument near Utah State Highway 211 (Utah 211) in Indian Creek Canyon, 28 road-kilometers (17 road-miles) from the GROA. Utah 211 will be used for access to the site during site characterization. This activity is discussed in Section 4.2.1.8. The increased traffic flow past the Monument and its facilities (campsites, picnic sites, etc.) will cause some disruption to visitation and overnight camping. Therefore, the DOE expects some significant adverse environmental impacts to the Newspaper Rock State Historical Monument due to an increase in noise and traffic levels sufficient to change the character of the area surrounding the monument. The DOE plans to review this finding with the BLM, the Utah SHPO, and the Advisory Council on Historic Preservation in accordance with the PMOA being developed.

Based on the analysis presented in Section 5.6.2.2, there will be no significant visual impact on Dead Horse Point State Park.

The evidence indicates that the potentially adverse condition is present.

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

Evaluation. The nearest significant Native American resources and sites of unique cultural interest are within the Salt Creek Archaeological District which lies along the eastern edge of Canyonlands National Park. As discussed in Sections 4.2.1.12 and 5.2.11, the impacts of the repository and support facilities on these resources are not expected to be significant.

The DOE does not consider the petroglyph panel at Newspaper Rock State Historical Monument to be a significant Native American resource because it is not believed to be a site of religious or other significance to existing tribes. The monument lies alongside Utah 211 in Indian Creek Canyon, 28 road-kilometers (17 road-miles) from the GROA.

The evidence indicates that the potentially adverse condition is not present.

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

Evaluation. Field surveys did not identify any critical habitat for threatened or endangered species in the immediate vicinity of the site. Peregrine falcons and other protected species are known to exist in the Gibson Dome area (Sections 5.2.4 and 4.2.1.2). Known habitats for any of these species are not expected to be compromised by site characterization or repository activities. The proposed rail route alternatives could potentially affect peregrine falcons which inhabit cliffs near the routes. However, literature surveys and contacts with Federal and State agencies indicate that corridors can be selected that do not compromise critical habitats of these threatened or endangered species (Section 5.3.2).

The Colorado River squawfish is known to be present in the reach of the Colorado River between its confluence with the Green River and the city of Moab. However, no critical habitat for the squawfish has been designated in this reach of the Colorado River (see 50 CFR 17.11 and 17.12, "Endangered and Threatened Wildlife and Plants," July 27, 1983) (Bolwahnn, 1984). If the Davis Canyon site is selected, a water-intake structure and a railroad bridge will be constructed somewhere along the Colorado River.

A potentially adverse condition is not present because there are no known or designated critical habitats for threatened and endangered species that could be compromised by the repository or its support facilities.

The evidence indicates that the potentially adverse condition is not present.

6.2.1.6.4 Analysis of Disqualifying Conditions

(1) During repository siting, construction, operation, closure, or decommissioning the quality of the environment in the affected area could not be adequately protected or projected environmental impacts in the affected area could not be mitigated to an acceptable degree, taking into account programmatic, technical, social, economic, and environmental factors.

Evaluation. The project has been designed with considerable mitigation measures included. The DOE has concluded that the quality of the environment in the affected area can be adequately protected. Residual environmental impacts, which are identified in Sections 4.2, 5.2, and 5.3 and in Table 6-5, have been shown to be either relatively short-term or of limited extent, or both. While some of these impacts will be felt in Canyonlands National Park and to some extent lessen the experience of a visitor to the Park, taking into account programmatic considerations, including the need to identify a licensable site from among sites that on a preliminary basis exhibit technical merit (the geology at the Davis

Canyon site has potential for possessing characteristics that would indicate an ability to isolate the waste effectively [see Sections 6.3 and 6.4]), the DOE finds on balance these residual environmental impacts of siting, constructing, operating, and decommissioning a repository are acceptable.

The evidence does not support a finding that the site is disqualified (Level 1).

> (2) Any part of the restricted area or repository support facilities would be located within the boundaries of a component of the National Park System, the National Wildlife Refuge System, the National Wilderness Preservation System, or the National Wild and Scenic Rivers System.

Evaluation. During the site selection process, all such lands were specifically excluded from consideration as potential repository sites (Section 2.2). Consequently, no part of the site is located within the boundaries of a component of the National Park System, the National Wilderness Preservation System, or the National Wild and Scenic Rivers System. Furthermore, based on the information presented in Section 3.4.1.3.2 (Figure 3-65) and Sections 4.2.1.10 and 5.1.2.2 (Figure 5-10), transportation and utility corridors to the site can be selected so they do not pass through such lands.

The evidence does not support a finding that the site is disqualified (Level 1).

> (3) The presence of the restricted area or the repository support facilities would conflict irreconcilably with the previously designated resource preservation use of a component of the National Park System, the National Wildlife Refuge System, the National Wilderness Preservation System, the National Wild and Scenic Rivers System, or National Forest Lands, or any comparably significant State protected resource that was dedicated to resource protection at the time of the enactment of the Act.

Evaluation. The closest such Federal land designated for resource preservation is the Canyonlands National Park, located within 1.6 kilometers (1 mile) of the proposed boundaries of the site. The discussions presented in Chapters 4 and 5, and in Section 6.2.1.6.3 indicate that the presence of a restricted area or repository support facilities at the site would not be expected to conflict irreconcilably with the previously designated use of any component of the National Park System, the National Wildlife Refuge System, the National Wilderness Preservation System, the National Wild and Scenic Rivers System, the National Forest Lands, or any comparably significant State-protected resource dedicated to resource preservation at the time of enactment of the Nuclear Waste Policy Act of 1982 (NWPA). No part of the restricted area or repository support facilities will be within the boundary of the park.

Potential effects of operation, closure and support facilities on Canyonlands National Park have been evaluated based on assumptions that provide bounding and conservative conditions.

Results of the evaluation of potential effects of the presence of repository support facilities and restricted area during operation and closure on the park are detailed in the following statements:

1. No detectable visual impairment due to atmospheric emissions will occur within the park during repository operation.

2. Emissions are not expected to have impacts on any plant species or cryptogamic soil crusts within the park.

3. Night skyglow during repository operation will be comparable to that originating from Moab. Repository operation is expected to have little impact on night sky watching.

4. No project-related odors are projected to be detectable in the park.

5. No air-quality emissions or ground shocks from explosives are projected to have any detectable impact on geological, archaeological, historical, or cultural resources.

6. Operating noises are projected to be nondetectable at all sensitive areas within the park except the park boundary nearest the site. This area is accessible only by foot. These impacts on park uses are not considered significant.

7. Noise impacts to wildlife within the park are expected to be insignificant.

8. Transportation noises can be mitigated to acceptable levels within the park by selecting access corridors which are not aligned with the park boundary.

9. Scenic resources within the park will not be affected. The project site will not be visible from any of the key observation points within the park. Each access-route alternative has one or more significant visual contrast rating impacts. None of these impacts are from key observation points in Canyonlands National Park. Each alternative access route has significant impact from one or more key observation points. None of these impacts are from key observation points in Canyonlands National Park. Significant visual impacts may occur as viewed from the Davis Canyon jeep trail and Utah 211.

10. All of the park except the moderate and high use zones is being proposed as a Wilderness Area. The Wilderness Area, if designated, would also include the Salt Creek Archaeological District, and the Old Spanish Trail. The Old Spanish Trail is not proposed as a designated historic trail. Major uses of wilderness areas include backpacking and primitive, pristine camping. Solitude would be protected in all but the park boundary area nearest the site during operation. After repository closure, there would be no impacts on solitude.

11. No significant impacts to the Colorado River water supplies are expected. Water can be obtained from current allotments. No new allotment needs are projected for repository operation.

12. Surface- and ground-water resources in the park will not be significantly impacted by repository operations because environmental controls will be used at the facility.

13. Impacts from increased visitors to the park as well as to archaeological and cultural resources are expected to be directly related to the increased number of operations staff. Increased cultural resource damage is expected to be similar to that expected from normal increases in visitation.

14. During repository operations, general visitor access to the park would be improved up Davis Canyon to the site. If a new road is constructed for facility operations, project traffic would not be shared on Utah 211.

15. Impacts from fugitive salt emissions to the park air quality, biota, soils, and water quality likely will not be detectable because most salt deposition is projected to occur on site.

Section 5.5.1.3 contains a discussion on the cumulative effect that repository-related activities would have on park resources. The analysis identified the recreational activities available within designated areas of Canyonlands National Park and evaluated the areal extent and duration of the environmental impacts. Significant long-term environmental impacts would result from audible equipment noise and the visual presence of the project. These long-term impacts would be limited to a small portion of the park in Davis Canyon (see Figures 5-30 and 5-31).

Short-term traffic delays during shift changes and movement of heavy equipment could potentially disturb park visitors coming to the Needles District. This impact could be mitigated by scheduling equipment movement when visitor traffic is low, and by posting the scheduled times of peak traffic so visitors could avoid delays. Furthermore, the annoyance could be eliminated by constructing an exclusive access road for the repository and its workers.

Long-term, audible machine noise and the visual presence of the repository could also potentially diminish the enjoyment derived from in-park activities available in Davis Canyon. While relatively few people visit Davis Canyon, the opportunity exists for them to view rock and desert formations, wild animals, Indian relics, and the stars. They could also come there to get away from people, hike off-trail, climb rocks, camp in a primitive area or drive an off-road vehicle. Tables 4-46, 5-49, and 5-50 illustrate that Davis Canyon is not unique because Upper Lavender Canyon in the Needles District offers the same or similar recreational opportunities for park visitors. It is also true that other areas in the Needles, Island-in-the-Sky, and Maze Districts of Canyonlands National Park provide similar activities.

The Canyonlands National Park was established to preserve an area "possessing superlative scenic, scientific, and archaeological features for the inspiration, benefit, and use of the public." Section 112(a) of the NWPA requires the DOE to publish general guidelines for recommendations of sites for repositories. The guidelines shall specify "factors that qualify or disqualify any site ... including factors pertaining to proximity to components of the National Park System ..." of which Canyonlands National Park is a part. Legislative history of this section indicates that mere proximity of the repository and its concomitant environmental impacts on a National Park do not alone disqualify an area, but that such an area should be designated only as a "last resort if none of the other alternative sites satisfy the essential criteria for a permanent repository" (128 Cong. Rec. H8778 [daily ed. Dec. 2, 1982]).

In implementing this statutory provision in the Guidelines, both potentially adverse conditions and disqualifying conditions were established. Sections 960.5-2-5(c)(2) and (3) present the potentially adverse conditions and are addressed above. Section 960.5-2-5(d) contains the three disqualifying conditions relevant to this provision of the NWPA. The first relates to the acceptability of the environmental impacts associated with all stages of repository siting, construction, operation, closure and decommissioning (Section 960.5-2-5 [d][1], "Disqualifier One"). As indicated previously, the DOE is of the view that the projected environmental impacts are acceptable when balanced against programmatic and technical, social, and economic considerations.

The Department of Interior (DOI), however, believes that any environmental impacts which may occur in the Park are "unacceptable" under its statutory mandates and therefore the siting, construction, operation, closure, and decommissioning of a repository would be in irreconcilable conflict with those mandates. In its comments, the DOI expressed the view that the Davis Canyon site should be disqualified. The DOI has a stated inability, because of its statutory mandate, to balance environmental impacts against the DOE's programmatic objectives pursuant to the requirements of the NWPA and other considerations (as the DOE must under the Disqualifier One). However, the DOE considers the DOI's comments to have identified many potentially adverse conditions. These have been mitigated and the residual impacts were important elements in our balancing under Disqualifier One. This balancing of considerations has included those environmental impacts and impacts on the intangible values mentioned by the DOI in expressing its view that repository siting, construction, operation, closure, and decommissioning would be in irreconcilable conflict with its duty to protect the Park. As discussed above the DOE has conducted this balancing and has concluded that the impacts are acceptable.

The second disqualifier relates to whether any part of the restricted area or repository support facilities would be located within the boundaries of a national park (Section 960.5-2-5(d) (2), "Disqualifier Two"). As also indicated above, no part of the restricted area or repository support facilities will be located within Canyonlands National Park.

Disqualifier Three (Section 960.5-2-5(d) (3), "Disqualifier Three"), implementing the statutory requirement that we specially consider "proximity" to a national park, provides that a potential site is disqualified if "the presence of the restricted area or the repository support facilities would conflict irreconcilably with the previously designated resource preservation use of [Canyonlands National Park]." The previously designated resource preservation use is contained in the Canyonlands National Park Act (16 USC Section 271).

The test under Disqualifier Three is different from the test under Disqualifier One. A site could be disqualified under Disqualifier Three even where the project's total environmental impacts are found by the DOE to be acceptable and no part of the restricted area or support facilities are to be located within the Park. In applying Disqualifier Three to this site, the DOE carefully evaluated the DOI's discussion of projected impacts and view that this site should be disqualified. For the reasons set forth below, after full consideration of the DOI's and other pertinent comments, we have concluded that this site is not currently disqualified under Disqualifier Three.

First, there have been several changes in the proposed project itself which provide further environmental mitigation. The DOI may want to review these changes and assess their effect on the conclusions they reached based on the draft EA. Second, the DOI's specific comments did not address the focus of Disqualifier Three. This disqualifier relates only to the presence of the restricted area (defined at Section 960.2) or repository support facilities (defined at Section 960.2) and does not apply to site characterization or construction. What is required to be considered for disqualification of a site under this criterion is whether the "presence of the restricted area or repository support facilities" are, or would be, in irreconcilable conflict with the resource preservation use of the Park which is established at 16 USC Section 271. After reviewing the final EA, the DOI may wish to render advice to the DOE as to their view on whether the presence of the restricted area or repository support facilities would be an irreconcilable conflict with the Canyonlands Authorization Act (16 USC Section 271).

On the basis of the DOE's review of available information on projected impacts to the Park from the presence of the restricted area or repository support facilities, the DOE cannot conclude that the presence of the restricted area and repository support facilities would be in irreconcilable conflict with the previously designated resource preservation use of the Park. The DOE cannot, therefore, say at this time that the site is disqualified. If, at any time, credible and relevant information comes to the DOE's attention that demonstrates that an irreconcilable conflict would in fact exist, then the site would be disqualified.

As discussed in Section 4.3.5, Newspaper Rock State Historical Monument, a protected resource, will experience significant impacts from noise and traffic. These impacts are expected to be limited to the site characterization period and the beginning of repository construction and will not extend to the operational phase and will not exist from the presence of the restricted area or support facilities.

The evidence does not support a finding that the site is disqualified (Level 1).

6.2.1.6.5 Conclusion for the Qualifying Condition.

Assessments of what is known about the site and affected area and the potential impact of preclosure repository activities provide reasonable assurance that requirements for the protection of the quality of environment can be met at the Davis Canyon site.

Favorable conditions for environmental quality are not present because of the following:

1. The DOE cannot project the "ability to meet, within time constraints, all Federal, State, and local procedural and substantive environmental requirements applicable to the site and the activities proposed to take place thereon."

2. Potential significant adverse environmental impacts cannot be mitigated to an insignificant level by using reasonable measures (Section 6.2.1.6.3).

Based on analyses of potential impacts on air quality, water quality, cultural resources, biota, land use, noise, and visual aesthetics, three potentially adverse conditions for the environmental quality guideline are present. These potentially adverse conditions are present because there may be significant adverse effects due to the following:

- Elevated noise levels on portions of Canyonlands National Park, a proposed Wilderness Area, and Bridger Jack Mesa, a Wilderness Study Area
- Adverse visual contrasts of railroad corridors from scenic viewpoints outside Canyonlands National Park
- A temporary and reversible significant adverse effect on Newspaper Rock State Historical Monument due to increased truck traffic and noise, during site characterization
- A temporary and reversible adverse effect on park visitors experiencing some inconvenience in driving with construction vehicles to access the park during the site characterization period (Section 6.2.1.6.4).

No other potentially adverse conditions are present because of the following:

1. No major conflicts with applicable environmental requirements are projected.
2. Air quality impacts will not be perceptible to park visitors and emissions will not exceed applicable standards designed to protect human health and to prevent material degradations.
3. No significant adverse effects on Native American or unique cultural resources are projected.
4. There is no designated critical habitat for threatened or endangered species in the project area.

None of the disqualifying conditions are present for the environmental quality guideline. This finding is reached because of the following:

1. The DOE believes that the quality of the environment in the affected area can be adequately protected, and projected environmental impacts can be mitigated to an acceptable degree, taking into account programmatic, technical, social, economic, and environmental factors.
2. No part of the restricted area or repository support facilities lie within federally protected lands.
3. The restricted area and repository support facilities will not conflict irreconcilably with resource-preservation use of Federal or State lands dedicated to resource preservation (Section 6.2.1.6.5).

Evaluation of Part 2 of the environmental quality, socioeconomic, and transportation Guidelines is presented in Section 6.2.2.2.1. This evaluation indicates that from the environmental perspective (and the others), the evidence does not support a finding that the site is not likely to meet qualifying condition 960.5-1(a)(2).

The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.2.1.7 Socioeconomic Impacts, Guideline 10 CFR 960.5-2-6

The objective of the Technical Guideline on socioeconomic impacts is to ensure that any significant adverse socioeconomic impacts of repository development can be offset by reasonable mitigation or compensation.

This guideline includes a qualifying condition, four favorable conditions, and four potentially adverse conditions for analysis. It also has one disqualifying condition.

6.2.1.7.1 Statement of Qualifying Condition.

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

Evaluation Process. The evaluation process consisted of (1) establishing baseline conditions with respect to the socioeconomic parameters identified in the guideline, (2) estimating total work force requirements for preclosure repository activities, (3) estimating the in-migrating portion of the work force and the associated increase in secondary labor demand, and (4) assessing changes in the socioeconomic conditions attributable to preclosure activities and the potential impacts to the projected socioeconomic environment without the repository. A summary of the evaluation is presented in Table 6-2.

Relevant Data. The existing socioeconomic profile (demography, labor force, community facilities, and other characteristics) of the region is discussed in Section 3.6 of this document. Specific socioeconomic and other related impacts from site characterization and repository development are discussed in Sections 4.2.2 and 5.4, respectively.

Assumptions and Data Uncertainty. The socioeconomic study area for the Davis Canyon site includes San Juan and Grand Counties in Utah. Socioeconomic impact projections are based on the current labor force estimates discussed in Section 5.4. Changes in the level of in-migration, employment, service needs, fiscal structure, and social structure depend heavily on labor force estimates. In addition, the ONWI Population In-Migration Model (Goldsmith, 1984) uses population and employment multipliers that are based on current literature, other project data, and professional judgment. The estimates do not assume any significant measures taken to raise the local hiring potential such as training programs in order to estimate total impacts to the study area. Analysis of socioeconomic impacts are based on existing conditions at the site area. A major assumption is that since the delivery of services such as water and sewage treatment is related to households, there will be adequate service capacity where housing capacity is adequate.

Analysis. An evaluation of socioeconomic impacts attributable to repository development is presented in Section 5.4. Results of the evaluation are summarized in Table 6-5.

6.2.1.7.2 Analysis of Favorable Conditions.

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

Evaluation. The projected net change in total population within Grand and San Juan Counties is expected to be approximately a 20 percent increase above the baseline population during the peak of in-migration (see Section 5.4). This level of regional population increase is considered to be a significant disruption to housing and community services. According to Section 5.4, the number of housing units needed by repository-related households could reach 1,600 units. There are fewer than half this number of units currently available in the study area (Section 3.6). As discussed in Section 5.4, considerable development of related community services would need to occur in many communities in these counties.

The evidence indicates that the favorable condition is not present.

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

Evaluation. The local work force is estimated to account for 19 percent of the required peak repository-related work force. This estimate is based on the assumption that no extraordinary measures are undertaken to increase local hiring (Section 5.4). Thus a large portion of the repository-related work force would be hired from outside the study area.

The evidence indicates that the favorable condition is not present.

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

Evaluation. Employment, business sales, and government revenues in the affected area are interrelated because an increase or decrease in any one of these factors will cause a similar increase or decrease in the others. If there is a net decrease in these factors, this condition will not be considered a favorable condition. While these factors are also related to the quantity of community services made available, the quality of services cannot be projected, because whether or not community services are improved is a policy issue to be resolved by local officials.

The projected annual employment growth rate attributed to repository-related activities is 3 percent of the total employment in the socioeconomic study area. The peak of repository-related employment is projected to supply work for about 2,000 people with 400 people now in the two-county area receiving new employment. Any potential loss of jobs in this economic area will be most likely related to a partial loss of tourism expenditures, principally from visitors who wanted primarily to visit Canyonlands National Park. Some people may avoid this park because they associate it with the repository development. Other major area tourist attractions such as Lake Powell, Arches National Park, and Monument Valley are not so identified. Since expenditures associated with Canyonlands National Park visitors are directly responsible for about 76 jobs, there will still be a significant net increase in area employment.

Direct local material purchases attributable to the repository are projected to average about 5.4 million dollars per year during the construction phase. This would result in an estimated 5 percent annual increase in the area's total sales (Section 5.4.2.2.1). This does not include the extent of worker purchases in the local economy. Purchases related to Canyonlands National Park visitors in 1983 was estimated to be about 1.1 million dollars per year (See Section 3.6.2.4). Therefore, it is anticipated that a significant net increase in business sales will result, even if some portion of the expenditures attributed to Canyonlands Park visitors is lost.

Construction of the repository will result in an increase in revenue from property taxes, sales taxes, and user fees. Property tax revenue will increase in those jurisdictions where workers choose to settle, and where residential and commercial real estate development occurs, thus increasing the amount of taxable property. Construction of the repository and related salaries will increase the personal income in the area, resulting in greater sales tax revenues from this source. Sales tax revenues will also increase from repository supplies that are purchased locally. User fees are related to specific services such as water supply or wastewater treatment. With the increase in project-related population, the revenues from user fees will increase. Section 5.4.5.1 includes information on intergovernmental transfer payments which offset government revenue loss due to the Federal purchase of land and the increased demand for services. These payments will include (1) grants-equal-to-tax payments, (2) impact mitigation funds, and (3) impact planning funds. The actual amounts of tax revenues cannot presently be estimated. Because there is no anticipated loss in local revenues, there will be a significant net increase in government revenues.

The evidence indicates that the favorable condition is present.

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

Evaluation. According to 1984 employment statistics, the major sectors contributing to the major employment of the area were (1) retail and service, 31 percent; (2) government, 24 percent; and (3) mining, 14 percent; disruption to one of these sectors is defined as a substantial net loss of employment in that sector.

The repository and related demands for goods and services would not affect those sectors exporting products outside the study area. In general, mining would be considered an exporting sector because it exports its raw products outside the study area and, therefore, the majority of its markets will be less affected than other local sectors. The demands on local government created by new growth should create jobs in the government sector.

As discussed in Section 3.6.2.4, tourism directly provided the equivalent of 475 person-years of employment for San Juan and Grand Counties in the combined retail and service sectors. This represented approximately 24 percent of the jobs in these sectors. Some of these jobs could be lost if potential tourists choose to avoid the area.

Major regional attractions such as Lake Powell, Arches National Park, and Monument Valley are not associated by name with the repository, but Canyonlands National Park is. Because Canyonlands National Park is adjacent to the facility, some tourists may choose to avoid the park. The total number of direct jobs associated with purchases made by tourists who had Canyonlands National Park as their primary destination was 76 person-years of employment. (See Section 3.6.2.4).

Based on Section 5.4.2, the expected number of local jobs created in the retail and service sectors directly related to purchases made by the project and its workers would average 240 person-years of employment during the construction phase and 230 person-years during operation. Therefore, while some jobs related to tourism in the retail and service sectors may be lost, many other jobs will be created in those sectors because the repository and its workers will be making local purchases.

The evidence indicates that the favorable condition is present.

6.2.1.7.3 Analysis of Potentially Adverse Conditions.

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

Evaluation. This condition relates to potential for significant adverse impacts. Based on the discussion in Section 6.2.1.7.2(1) demand for housing, schools, sewer lines, and other services will be significant. The actual change in revenues and expenditures cannot presently be estimated. The communities of Moab, Monticello, and Blanding are projected to have a peak year (1997) cumulative growth of 31 percent, 50 percent, and 24 percent respectively (Section 5.4). The growth rate would occur over a 6-year period; however, the cumulative growth would cause significant impacts.

The evidence indicates that the potentially adverse condition is present.

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

Evaluation. Less than 20 percent of the available repository-related jobs will be held by local residents.

The evidence indicates that the potentially adverse condition is present.

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

Evaluation. The water requirements for the repository have been identified in Table 5-1 (Section 5.1.1). The average repository water requirements during the construction phase would be 0.199 million cubic meters (161 acre feet) per year. The average water requirements during the operation phase would be 0.371 million cubic meters (301 acre feet) per year.

A review was performed to evaluate the water resources of the area and its allied water input issues (SCC, 1984). A variety of potential water sources exist in the area. A likely source of the water is the San Juan County Water Conservancy District (SJC-WCD) which has jurisdiction over the project site. SJC-WCD has indicated that it would enter into agreement for the sale or lease of up to 2,800 acre-feet annually of the waters of the Colorado River or one of its tributaries during construction and up to 500 acre-feet of water annually for operation of the repository (Nielson, 1984). Other potential sources include purchase or lease of existing private water rights along the Colorado River or one of its tributaries (SCC, 1984). One alternative being considered is the consolidation of acquired water rights to a single point of diversion of water from the Colorado River downstream of Moab where a pumping station and pipeline could be constructed to the repository site. Such a change in the authorized point of diversion would be subject to appropriate regulations.

Because the San Juan Planning Council (1983) expects that the building of two new reservoirs in the Blanding and Monticello area will take care of economic development needs and is willing to sell or lease part of its appropriation, it is assumed that present development will not be adversely affected. There is no expectation that acquisition of repository water rights will conflict with the future development of the region.

The evidence indicates that the potentially adverse condition is not present.

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

Evaluation. A favorable condition was shown in part (4) of Section 6.2.1.7.2, therefore a major disruption of the primary sectors is not expected. The increase in the retail and service sectors of the local economy attributed to the repository and worker purchases will offset a loss of tourism expenditures in the two-county region.

The evidence indicates that the potentially adverse condition is not present.

6.2.1.7.4 Analysis of Disqualifying Condition.

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

Evaluation. No significant effect on the water quality of the Colorado River is expected (Section 5.2.2.1). Ground-water quality is to be protected by facility design and protection measures (Section 5.2.2.2). Impacts of repository development on water quality are expected to be short-term and not significant enough to disrupt the long-term development of crop irrigation and other future development (Section 6.2.1.7.3).

The evidence does not support a finding that the site is disqualified (Level 1).

6.2.1.7.5 Conclusion for the Qualifying Condition. A favorable condition was not present for population growth impacts on housing and local services, and the availability of an adequate labor force. A favorable condition was found for net increases in local government, business sales, disruption of the primary sectors and increased government revenues. Lack of housing, community services, and labor were evaluated as being potentially adverse conditions.

An adverse condition resulting from the repository-related purchase of water rights was not present. Housing and other services can be provided under the mitigation provisions of the NWPA. While local labor is inadequate to meet repository needs, mitigation measures suggest that the effect of this condition can be minimized such that the performance of the system will be acceptable. Several ways are available to provide an adequate labor force for the repository while minimizing impacts: (1) take advantage of available skilled labor already in the affected area, and (2) train potential out-migrants (area unemployed, under-employed, or young adults) for skilled positions so they can remain in the area.

The disqualifying condition is not present because it is expected that water supplies will not be affected and that there will not be impacts to water quality.

The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.2.1.8 Transportation, Guideline 10 CFR 960.5-2-7

The objective of the transportation guideline is to ensure that proper consideration is given to the transportation of waste to a repository site. This transportation could affect the health and safety of the public, the environment, and the cost of waste disposal. The guideline requires the evaluation of a site's proximity to adequate highways and railroads, the characteristics of access routes from existing highways and railroads to the site, the costs and other impacts of designing and constructing the access routes, and the impacts of transporting waste over the access routes. The guideline indirectly requires consideration of proximity to the sources of waste because one of the favorable conditions is stated in terms of a comparison of costs and risks among sites.

This guideline includes a qualifying condition, nine favorable conditions, and four potentially adverse conditions for analysis. It does not have a disqualifying condition.

6.2.1.8.1 Statement of Qualifying Condition.

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

Evaluation Process. Transportation access routes from the local and regional network were examined to determine viable routes for repository transportation requirements. This evaluation process includes an examination of (1) conflicts with protected Federal and comparable State lands, (2) construction methods using available technologies, (3) compliance with U.S. Department of Transportation (DOT) and NRC requirements, (4) potential for causing unacceptable risks to public health and safety, and (5) mitigation of environmental and transportation infrastructure impacts. In order to ensure that all sites were evaluated in a consistent manner, a common set of criteria was developed by the DOE. These criteria were quantified and also stated in the evaluation of each guideline, and further discussed in Appendix A.

The nationwide sources of waste, along with types and quantities of waste destined for the repository, were estimated and are summarized in Appendix A. Local highway and railroad access routes from existing elements of the national transportation system to the site were

identified to examine types of impacts that might be experienced. Where the evaluation requires comparison with other sites, the comparison is given in Chapter 7.

Relevant Data. The existing transportation system in the vicinity of the site is presented in Section 3.5. A description of the rail and highway access routes (used to evaluate the site against the guideline) as well as transportation impacts and transportation route adequacy are discussed in Sections 4.2.1.1.0, 4.3.5, 5.1.2.2, 5.3.1, 5.3.2, and 5.3.3. Pertinent data used in this evaluation are summarized in Table 6-6.

Assumptions and Data Uncertainties. Railroad operations assume the switching of cars at Grand Junction, Colorado or Helper, Utah on the Denver and Rio Grande Western (D&RGW) Railways and delivery to the Cane Creek branch line which will connect to the repository railroad. The highway access route is assumed to connect with U.S. Highway 191 (U.S. 191) which connects with Interstate 70 (I-70) on the north and Interstate 40 (I-40) on the south. These routes were identified to aid in the assessment of transportation impacts.

The analysis is based on transportation facilities and conditions existing in 1985. Rail and highway traffic volumes and patterns could change by 1998, which in turn could require construction of new facilities, abandonments, and changes in maintenance practices and physical condition of facilities. It is assumed that repository personnel would operate the railroad over track constructed between the site and the existing D&RGW Cane Creek branch rail line.

Protected Federal and State lands that are near the site and the transportation access routes are described in Section 3.4.1. Meteorological data for the area are described in Section 3.4.3. Radiological and nonradiological risks to the public health and safety from nuclear waste transportation are discussed in Section 5.3.1.

Cost data are given in 1984 or 1985 dollars as noted. No land-acquisition costs are included. The alternative access routes are used only as a basis for assessing the impacts associated with nuclear waste transport to the site. Before preferred routes are selected, detailed studies and evaluation, and consultation with the State and local officials will be required.

Analysis. The access routes connecting the repository site with the rail and interstate highway systems are described in Section 5.1.2.2. The design, engineering, and construction of the access routes will employ conventional civil highway and railway-engineering practices. No unique technologies are required. Transportation-related construction and operation will be carried out in a manner which protects the public health and safety and environmental quality.

6.2.1.8.2 Analysis of Favorable Conditions.

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

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

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

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

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

(v) Such routes bypass local cities and towns.

Table 6-6. Site Transportation Data - Davis Canyon

Repository Access Routes - New Construction[a]	Truck[b]	Rail[c]
Length - Miles	5-25	38-54
Terrain Description	Very rugged	Very rugged
Number of Tunnels	0-2	1-3
Number of Bridges	0-8	13-18
Number of River/Lake Crossings	None	1
Acquisition of Private Land Required	No-Yes	Yes
Overall Cost - $ Million[d]	3.2[e]-79	141-269
Existing Highway/Railroad Network[a]		
Length of Upgrade - Miles	96-64/68[f]	0
Cost of Upgrade - $ Millions[d]	20/40[f][g]-15/35[f]	0
Distance to Interstate Highway/ Mainline Railroad from Access Route - Miles	96 North-64 North[h] 195 South-173 South	30-36
Transportation Operations - Authorized System[i]		
Total Loaded Vehicle-Miles Traveled - Millions	145.1	25.5
Life Cycle Cost - $ Millions	1,305	1,207
Life Cycle Risks		
Non-Radiological		
Number of Injuries	380	25
Number of Fatalities	30	2.6
Radiological-Number of LCF's		
Normal Conditions	9.5	0.3
Accidents	0.03	0.02

(a) From Section 5.1.2.2, except as noted.

(b) Ranges given represent use of Utah 211 upgrade (first number) versus the exclusive use access road (second number).

(c) Ranges given cover the four alternative rail routes.

(d) 1985 dollars, except as noted; land acquisition costs not included.

(e) From SCC, 1984.

(f) From SCC, 1984 (lower numbers) and Martinez, 1985 (higher numbers).

(g) Utah 211 lane widening, paved shoulders, turnouts, and 3-lane design on grades not included.

(h) From Section 3.5; North to I-70 via U.S. 191 and South to I-40 via U.S. 191 & 666.

(i) From Section 5.3.1 and Appendix A.

Evaluation. In application of the guideline to determine the presence of the above favorable conditions, the following criteria have been used:

(i) Short and economical means less than 16 kilometers (10 miles) and less than $10 million are considered favorable.

(ii) Acquisition of land for an access route which crosses private land will most likely require condemnation proceedings.

(iii) The need for tunnels or bridges along an access route is considered unfavorable. However, cuts and fills over generally flat terrain are considered insignificant.

(iv) Generally flat terrain is considered favorable.

(v) Passing through local cities and towns is considered unfavorable if the population of the city or town in an incorporated area is greater than 2,500 people or if the population density is greater than 1,000 people in a 1.6-kilometers-by-1.6 kilometers (1-mile-by-1-mile) area of the city or town.

In applying the above criteria, both highway and railroad access-route characteristics must be favorable to consider the site favorable with respect to each condition. If any one of the alternative routes do not meet the favorable condition, a not present finding will be made. The presence of any one of the five route characteristics is sufficient for a determination of favorability on the overall group of five.

At the Davis Canyon site, highway and railroad access routes will be relatively difficult to construct because of the rugged terrain. For the exclusive-use highway access route, new construction will be relatively long (approximately 40 kilometers [25 miles]), and also costly to construct (approximately $79 million). The railroad access route alternatives range from 61 to 87 kilometers (38 to 54 miles) in length and may cost up to $269 million. Rights-of-way for both truck and rail access routes will cross isolated parcels of private land and Federal condemnation proceedings may be required. Numerous cuts, fills, tunnels, and bridges will be required. Alignments will include curves and grades that are operationally acceptable, but sharper and steeper than normally found in flat terrain. Special precautions will also be required for the possibility of rock slides. One of the alternative rail access routes passes through the town of Moab whose population and population density are greater than the criteria above.

Based on the above information, the evaluation of access route characteristics is summarized as follows:

Route Characteristics	Finding
Short and economical to construct	Not present
Federal condemnation not required	Not present
Cuts, fills, tunnels, bridges not required	Not present
Free of sharp curves and steep grades	Not present
Local cities and towns bypassed	Not present

The evidence indicates that the overall favorable condition on access route characteristics is not present.

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

Evaluation. In application of the guideline to determine the presence of this favorable condition, the distance from the outer end of the newly constructed access route to the nearest highway or railroad which does not need significant upgrading is considered. If such

distance is less than 16 kilometers (10 miles) and upgrade cost less than 10 million dollars for each of the highway and railroad routes, the favorable condition is present. At the Davis Canyon site, significant upgrading of U.S. 191 and possibly U.S. 666 will be required at several points over the 430 kilometers (270 miles) between I-40 and I-70. Upgrading costs may range up to 40 million dollars. However, no significant upgrading of the D&RGW existing Cane Creek branch railroad is needed.

The evidence indicates that the favorable condition is not present.

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

Evaluation. In application of the guideline to determine the presence of this favorable condition, the distance from the outer end of the newly constructed access route to the nearest interstate highway and mainline railroad is considered. If such distance is less than 48 kilometers (30 miles) for both the highway and railroad routes, the favorable condition is present.

At the Davis Canyon site, the distance from the highway access route to I-70 is approximately 102 kilometers (64 miles) and that from the railroad alternative access routes range from 48 to 58 kilometers (30 to 36 miles).

The evidence indicates that the favorable condition is not present.

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

Evaluation. In application of the guideline to determine the presence of this favorable condition, the number of interchanges expected within the region based on routine deliveries in regular freight service from various points in the United States is considered. Interchange points are important because radiation exposure, even though very low, is related to railcar stopped time. A radius of 200 kilometers (125 miles) around the potential repository site is used to define the "regional railway system" in which interchange points are counted. This is believed to be a large enough area to include the convergence of all major rail lines from points throughout the United States that could be used for nuclear waste traffic. Interchange points include points where different railroads exchange cars, where the same railroad switches cars on its own system from one train to another, and where crew changes are made. The one site with the fewest interchange points is considered to have the favorable condition present. Comparison with other sites is given in Chapter 7.

Several national rail carriers feed into the Utah-Colorado area but only one rail carrier actually would serve the Davis Canyon site. The Denver & Rio Grande Western Railroad Company (D&RGW) is the only rail carrier offering service between Denver, Colorado and Salt Lake City, Utah. Thus, only two route combinations apply to this analysis. These routings would allow waste to enter the region from either direction and any shipment origin. The routes are displayed in Table 6-6 along with the type and number of interchange points per routing. Table 6-7 shows that the total number of all interchanges per routing is three, regardless of the route actually used.

The evidence indicates that the favorable condition is not present.

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

Table 6-7. Davis Canyon Railway System Interchanges

Possible Routes	Number of Potential Interchanges in 125-Mile Radius Per Routing			
	Inter-Carrier	Inter-Train	Crew	Total
D&RGW[a] (Westbound) - Grand Junction - D&RGW - Thompson[c] - D&RGW Potash - RRR[b]	1	1	1	3
D&RGW (Eastbound) - Helper - D&RGW - Thompson - D&RGW - Potash - RRR	1	1	1	3

(a) D&RGW = Denver and Rio Grande Western Railroad.
(b) RRR = Repository Rail Route.
(c) Thompson Interchange point currently uncertain; it may be changed to Grand Junction in the future.

Evaluation. The estimates of national life-cycle costs and risks associated with nuclear waste transport are are summarized in Table 6-6. Regional risks were also estimated and are discussed in Section 5.3.1. The purpose of the analyses was to provide conservative estimates of the risks and costs. In the evaluation of sites against this condition, only one site will have the favorable condition present. Comparison with other sites is given in Chapter 7.

The evidence indicates that the favorable condition is not present.

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

Evaluation. In application of the guideline to determine the presence of this favorable condition, the availability of one or more qualified and willing motor truck and rail carriers is considered favorable. The primary criteria used for the selection of highway carriers are whether the carrier has authority to haul nuclear commodities and can offer direct service between nuclear power plant sites and the potential repository site. There are two categories of motor carriers which could potentially meet these requirements.

The first category is special commodity, which consists of irregular route carriers who have nationwide authority. These carriers offer specialized service for specific commodities. The Interstate Commerce Commission (ICC) often grants operating authority to offer this service between points in most of the contiguous United States. Carriers with authority to haul either radioactive materials or hazardous materials are automatically included in this group. Those with authority to carry either nuclear components or explosives are also included. It is assumed that these carriers would have the experience to justify ICC approval to include radioactive materials in their operating authority. Six highway carriers were found to have such authority.

The second category is general commodity, consisting of regular route carriers which have authority to serve the town closest to the repository site and also authority to serve numerous points in other states. These carriers meet the criterion of offering direct service between numerous states in which nuclear facilities are located and the prospective repository location. Those general commodity carriers with authority to carry hazardous materials and which participate in the American Trucking Association (ATA) Hazardous Materials Tariff are included in this group. Also carriers which have a special commodities division within their organization are included. The assumption here is that these carriers have the experience and equipment necessary to offer the specialized service required for nuclear waste transport and that ICC authority could be obtained for nuclear waste since the carrier already has authority to serve the repository location. Two highway carriers were found to have such operating authority servicing the region under consideration.

A total of eight highway carriers were identified to have the capability to handle waste shipments to the repository. This number may change frequently between now and 1998; however, a multiplicity of highway carriers are expected to be available.

The primary criteria for rail carriers are that they be Class I carriers (defined by the ICC as having operating revenues over $50 million annually) and have mainline tracks within a 200-kilometer (125-mile) radius of the potential repository site.

There is one Class I railroad which has a mainline track within the 200-kilometer (125-mile) radius of the Davis Canyon site. The Denver & Rio Grande Western Railroad (D&RGW) provides the primary rail service between Salt Lake City, Utah and Denver, Colorado. It is the only carrier serving western Colorado and eastern Utah in the

general vicinity of the Paradox Basin. The D&RGW interconnects with the Union Pacific and Southern Pacific serving western states in Salt Lake City. From the east, D&RGW can receive traffic in Denver or Pueblo, Colorado from Union Pacific, Atchison, Topeka and Santa Fe (ATSF), Burlington Northern (BN), and Missouri Pacific (now a part of Union Pacific).

There are no navigable waterways which could be used to directly serve the Davis Canyon site and accordingly, water carriers were not considered. However, the DOE national transportation program may eventually include barge transportation (see Section C.2.4.1) in which case water carrier availability will be considered.

In general, highway carriers have expressed considerable interest and willingness to offer nuclear waste transportation services and several are now actively engaged in such business. The railroads, through their trade association, Association of American Railroads, have expressed in the past some reluctance to haul nuclear waste. However, more recently, it is no longer a matter of willingness, but a matter of services, conditions, and appropriate rates which needs to be resolved. See Appendix A for more information on this subject.

The evidence indicates that the favorable condition is present.

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

Evaluation. This guideline favorable condition requires the consideration of state or local transportation rules or ordinances which are inconsistent with Federal regulations and would be an impediment to transportation of nuclear waste to the repository.

Since the DOT regulation of highway routing of radioactive materials 49 CFR 177.825 has been established as valid by the U.S. Supreme Court, the only legal impediment is a State or local rule which renders compliance with HM-164 impossible but which is found not to be preempted under provisions (112[b]) of the Hazardous Materials Transportation Act (HMTA) (49 USC Sections 1801-1812). If such a finding cannot be made, any State or local rule which prevents or seriously impedes compliance with 49 CFR 177.825 (HM-164) is preempted by the HMTA (112[a]). Because State or local laws or regulations restricting the transport of nuclear waste that are inconsistent with either the HMTA or the DOT's regulations issued thereunder are preempted by the HMTA, such laws or regulations in the affected or adjoining states are not considered legal impediments. A more extensive discussion is given in Section C.2.4.1.

The evidence indicates that the favorable condition is present.

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

Evaluation. The State of Utah has one comprehensive plan for responding to all types of natural and engineered emergencies. This plan is consistent with the Federal Emergency Management Agency (FEMA) approach to integrate all emergency planning under one comprehensive program. Annex U of the Plan is entitled Hazardous Materials (Utah Office of Emergency Services, 1977). Hazardous materials are classified as chemical, biological, explosive, and radiological materials for purposes of emergency response. The hazardous material plan covers "any situation in which accidental release of hazardous materials occurs," thus including fixed facility and transportation incidents.

The Department of Public Safety, Division of Comprehensive Emergency Management, has prime planning responsibility for hazardous material spills. The State Department of Health, Division of Occupational Health and Radiation Control provides expertise for radiological incidents.

Utah recently completed a radiological response plan which is separate and distinct from the general hazardous material response plan in Annex U. Since there are no nuclear power

plants in Utah, much of the radiological response plan centers upon transportation incidents. The Utah Bureau of Radiation Control, the Utah Comprehensive Emergency Management Division, and the Utah Highway Patrol coordinate planning in this document.

Finally, an important part of State planning for radiological emergencies is the capability to call upon Federal resources. If requested by the State, key Federal agencies provide for State and local assistance through the Federal Radiological Emergency Response Plan (FRERP) (Federal Emergency Management Agency, 1984) which is discussed in more detail in Appendix A. In addition, the DOE will prepare an emergency preparedness plan for the Davis Canyon repository project in accordance with the DOE Order 5500.3 which will support State and local plans. See Section 6.2.1.2.4 for additional information.

The evidence indicates that the favorable condition is present.

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

Evaluation. The intent of this condition is to require consideration of site-specific weather conditions that could frequently (several times a year) block access to the site for significant periods of time (several consecutive days) to such an extent that the repository would not meet its annual waste acceptance rate. Such a blockage, to be of concern, would have to occur on the final transportation links from the regional highways and railroads. For the Davis Canyon site, these highway links are U.S. 666 and U.S. 191, and the repository access road. Via railroads, the D&RGW Cane Creek Branch Railroad and connecting repository railroad are the connecting links.

Based on the meteorological data in Section 3.4.3, the likelihood of weather causing significant transportation disruptions is very low. Wintertime blockage which occurs occasionally on I-70 in the Colorado area can be accommodated by using alternative routings which could be specified before shipment departure from distant origin points or while enroute. These alternative routes include:

- From the East: I-40 to U.S. 666 to U.S. 191
- From the Northwest: I-15 to I-70 to U.S. 191
- From the Southwest: I-15 to I-70 to U.S. 191 and I-15 to I-40 to U.S. 666 to U.S. 191.

The evidence indicates that the favorable condition is present.

6.2.1.8.3 Analysis of Potentially Adverse Conditions.

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

Evaluation. In application of this guideline condition, a cost of truck or rail access route greater than $10 million is considered expensive. At the Davis Canyon site, the alternative exclusive use highway access route is estimated to cost $79 million and rail access route may cost up to $269 million.

The evidence indicates that the potentially adverse condition is present.

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

Evaluation. In application of this guideline condition, the presence of other than generally flat terrain and the need to cross rivers or lakes is considered potentially adverse.

The terrain at the Davis Canyon site is generally rugged; a river crossing will be required, and there is a potential for rock slides.

The evidence indicates that the potentially adverse condition is present.

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

Evaluation. In application of this guideline condition, needed upgrading of either existing local highways or railroads which would cost more than $10 million is considered significant. At the Davis Canyon site, upgrading on U.S. 191 and possibly U.S. 666 and Utah 211 will be required at a number of points over these routes between I-70 and I-40. Upgrading costs are expected to exceed $10 million. However, no significant upgrading of the existing D&RGW railroad line will be required.

The evidence indicates that the potentially adverse condition is present.

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

Evaluation. The costs and related environmental impacts of providing access to the Davis Canyon site are significantly greater than for other sites. Comparison with other sites is presented in Chapter 7.

The evidence indicates that the potentially adverse condition is present.

6.2.1.8.4 Analysis of Disqualifying Condition. The transportation guideline does not have a disqualifying condition.

6.2.1.8.5 Conclusion for the Qualifying Condition. Several feasible highway and railroad access routes to the site have been identified that do not irreconcilably conflict with a National Park System, National Wildlife Refuge System, National Wilderness Preservation System, National Wild and Scenic Rivers System, or National Forest Lands. Based on recent studies (Section 5.1.2.2), these routes can be designed and constructed using available technology. It is also believed that existing waste transportation packaging standards and containment technology are adequate for operations over these routes; nevertheless, potential hazards specific to certain alternative routes will be studied to determine if additional precautions or controls are required. A preliminary evaluation of operations over highway and railroad access routes to the site indicates that waste transportation operations can be conducted over these routes without unacceptable risk to the public or unacceptable environmental impacts, and adequate protection of the public and the environment can be provided, during both construction of the access routes and operation over those routes. However, additional study of alternative access routes to balance construction costs and environmental impact mitigation costs will be carried out during site characterization. Selection of the preferred highway and railroad access routes will include participation of State and local officials.

The evidence does not indicate that the site is not likely to meet the qualifying condition (Level 3).

6.2.2 Preclosure System Guidelines

As defined in 10 CFR Part 960, each System Guideline has an associated set of Technical Guidelines. The performance requirements that a repository must satisfy are specified in the System Guidelines. The site conditions representing principal determinants as to whether a site has the requisite characteristics for satisfying the performance requirements are defined in the Technical Guidelines.

In Section 6.2.1, site conditions defined in the Technical Guidelines pertinent to preclosure performance assessment and not requiring site characterization were examined individually. In this section, 6.2.2, sets or clusters of site conditions are evaluated in the context of their interactive and integrated contribution to satisfying preclosure System Guideline requirements.

The preclosure System Guidelines (10 CFR 960.5-1) consist of three parts (960.5-1[a][1], [2], and [3]). The first two, preclosure Radiological Safety and Environment, and Socioeconomics and Transportation, are treated in this Section (6.2.2), because they involve the Technical Guidelines not requiring site characterization (see Section 6.0 and 6.1 for explanation). The third part of the preclosure System Guidelines is 960.5-1(a)(3), Ease and Cost of Construction, Operation, and Closure. It includes Technical Guidelines that do require site characterization and is addressed in Section 6.3.4.

6.2.2.1 Preclosure Radiological Safety, Guideline 10 CFR 960.5-1

For preclosure radiological safety (10 CFR 960.5-1[a][1]), the pertinent system elements are (1) the site-specific characteristics that affect radionuclide transport through the surroundings; (2) the engineered components whose function is to control releases of radioactive materials; and (3) the people who, because of their location and distribution in unrestricted areas, may be affected by radionuclide releases. This guideline is assigned the greatest importance among the preclosure system guidelines because it is directed at protecting both the public and the repository workers from radiological exposures.

Although the guidelines specify compliance with regulations "during repository operation and closure," the operational phase is interpreted broadly in this analysis to include all periods during which radioactive emissions might occur (i.e., construction and operation).

6.2.2.1.1 System Guideline Requirements. Part (1) of 10 CFR 960.5-1(a), Preclosure Radiological Safety, defines the requirements for preclosure radiological safety as follows:

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

The specific requirements of these regulations are detailed in Section 6.4.1, where they are used for comparison with results of radiological analyses for the Davis Canyon site.

6.2.2.1.2 Evaluation Process. Those system elements pertinent to achieving compliance with System Guideline requirements are evaluated as an integrated whole system. The evaluation focuses on potential exposure of the public. Estimated exposure levels are compared with regulations established for protection of health and safety. A generic repository design of the type likely to be constructed, such as that described in Chapter 5, was evaluated to establish the inventory of radionuclides that might be released during construction and operation. For construction, this consisted largely of naturally occurring radioactive radon and related decay products released from entrapment in the mined material. For the operational period, a small inventory of radionuclides postulated to result from leakage from damaged spent fuel elements were assessed to be the source term. To estimate concentration levels at the point of release to the atmosphere, these source terms were assumed to be diluted by ventilation air exhaust volume and releases to the atmosphere through the stack.

Based on a restricted area of approximately 160 hectares (400 acres) (Figure 3-2), a distance to the restricted area boundary of 240 meters (800 feet) was estimated. Exposure levels to an individual, assumed to live at the boundary, were calculated for all potential exposure pathways - inhalation, submersion, and ingestion. Meteorological dispersion of the stack-released concentrations was based on estimated meteorological conditions, which reflected poor dispersion characteristics because the micrometeorological characteristics of this site remain to be evaluated.

Potential exposures to the public surrounding the site were estimated using source terms and meteorology described above, together with demographic data showing population distributions in relation to wind directions and distances from the site boundary.

A set of accidental events was postulated to cause releases of radionuclides from the repository. The consequences in terms of exposures to the paths were evaluated.

The work force radiological environment will be determined by the amount of radon released during the mining operations and the radiation shielding provided for protection from the waste packages. Site-specific designs will reflect these considerations. No specific analysis has been performed for this EA for the following reasons:

1. Salt represents a medium much less likely to emit radioactivity than uranium during mining. Uranium mining is accomplished within occupational health and safety standards. Hence, the feasibility to design mine ventilation systems to prevent excess radiation exposures in a salt mine is not a site-suitability issue.

2. Waste package handling methods will be used to prevent overexposure of individuals.

Relevant Data. Descriptive information on system elements pertaining to this System Guideline can be found in the following sections:

- Demography (Section 3.6.1)
- Meteorology (Section 3.4.3)
- Site Boundaries (Section 3.1)
- Offsite Installation (Section 3.6)
- Facility Design (Section 5.1)
- Source Terms (Section 6.4.1).

Data Assumptions and Uncertainties. Results of this analysis should be viewed in the context of assumptions and uncertainties set forth below. Additional detailed assumptions are described by Waite et al. (1985, BMI/ONWI-541, Rev. 1). The effect of these assumptions is to predict what is believed to represent an upper bound for radiological exposures during the preclosure period.

Principal assumptions are as follows for each of the following topics:

Source Terms. Source terms have been estimated for a generic facility design. The radionuclides anticipated to be released during construction, before the waste arrives, consist of naturally occurring radon and its decay products. Operational releases attributed to pin cladding damage during disassembly of spent fuel assemblies. Naturally occurring radionuclides were assumed to be released from ground level; operational releases were assumed to occur from an elevated stack.

Meteorology. Meteorological dispersion parameters for assessing offsite radiation levels from normal operations were derived from very conservative assumptions. For the accident scenarios, very poor meteorological conditions (F Class Stability and 1 meter-per-second [3.3 feet per second] wind speed), independent of the site, were conservatively assumed.

Demography. Demographic distribution of data is based on 1980 census information. Such data are regionally accurate but do not provide the detail for depicting the near-site setting.

Facility layout. Exact locations of the ventilation shaft and stack have not been established. A distance of 240 meters (800 feet) from the boundary of the restricted area is assumed.

6.2.2.1.3 Analysis. An analysis of the potential radiological impacts of preclosure repository activities at the Davis Canyon site is presented in Section 6.4.1. The results of this systems analysis, based on evaluation of the site against the requirements of the System and associated Technical Guidelines, are presented in Table 6-8.

Table 6-8. Preclosure System Guidelines Not Requiring Site Characterization, Davis Canyon

System Guideline	Associated Technical Guidelines	Assessment Results	Finding
Preclosure Radiological Safety. System Guidelines 10 CFR 960.5-1(a)(1) Qualifying Condition defines the requirements for preclosure radiological safety as follows: "Any projected radiological exposures of the general public and any projected releases of radioactive materials to restricted and unrestricted areas during repository operation and closure shall meet the applicable requirements set forth in 10 CFR Part 20, 10 CFR Part 60, and 40 CFR 191, Subpart A."	Population Density & Distribution 10 CFR 960.5-2-1 Site Ownership & Control 10 CFR 960.5-2-2 Meteorology 960.5-2-3 Offsite Installations 10 CFR 960.5-2-4		The evidence does not support a finding that the site is not likely to meet the qualifying condition.
		Technical Guidelines:	
	Population Density & Distribution (Section 6.2.1.2)	The site is located in an isolated, low population area.	
	Site Ownership and Control (Section 6.2.1.3)	Land for the repository can be obtained.	
	Meteorology (Section 6.2.1.4)	Meteorologic conditions at the site are not known. However, based on regional data, it is anticipated that requirements in this guideline can be met.	
	Offsite Installations (Section 6.2.1.5)	The site is located well away from any offsite installations or operations. However, there is and has been uranium mining and milling near the site.	
10 CFR 960.5-1(a)(2) Environment, Socioeconomics, Transportation. System Guideline 10 CFR 960.5-1(a)(2) Qualifying Condition defines the requirements for environment, socioeconomic, and transportation as follows: "During repository siting, construction, operation, closure, and decommissioning, the public and the environment shall be adequately protected from the hazards posed by the disposal of radioactive waste."	Environmental Quality 10 CFR 960.5-2-5 Socioeconomic Impacts 10 CFR 960.5-2-6 Transportation 10 CFR 960.5-2-7	System Guideline: Analysis (Section 6.2.2.3) shows that a variety of localized impacts will be experienced. These include (1) increases in the noise levels mostly during site clearing and repository construction; and (2) changes in localized traffic flow.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

Table 6-8. Preclosure System Guidelines Not Requiring Site Characterization, Davis Canyon
(Page 2 of 3)

System Guideline	Associated Technical Guidelines	Assessment Results	Finding
		It is unlikely that air-quality, noise, and visual impacts can be mitigated to an insignificant level. Some inmigration of workers can be expected with attendant needs for community facilities and support services. Socioeconomic impacts can be relieved by mitigating measures. Increased payroll and stimulated sales should enhance the economy of the affected areas.	
	Environmental Quality (Section 6.2.1.6)	Technical Guidelines: Assessments of what is known about the site and surrounding area and the potential impact of preclosure repository activities provides a reasonable basis for confidence that requirements for the protection of the public and the environment can be achieved at the Davis Canyon Site. This conclusion should be viewed within the context of assumptions and data uncertainties presented in Section 6.2.1.6.2. Respository construction and operational activities will result in releases off site of very small amounts of radioactivity, mostly from disturbing radon entrapped in the mined formations. As a result, analyses (Section 6.4.1) indicate that radiological health and safety requirements can be met with considerable margins. Air-quality, noise, and visual impacts can be acceptably mitigated to prevent significant adverse environmental consequences.	

Table 6-8. Preclosure System Guidelines Not Requiring Site Characterization, Davis Canyon
(Page 3 of 3)

System Guideline	Associated Technical Guidelines	Assessment Results	Finding
		There is reasonable basis for confidence that the System Guideline environmental conditions specified in 10 CFR 960.5-1(a)(2) can be met.	
	Socioeconomic Impacts (Section 6.2.1.7)	Projected impacts to socioeconomic sectors could result from needs for services imposed on local communities from in-migration of workers. Local housing units and labor force supply during peak activity periods will be inadequate for repository development. Impacts of in-migration are reduceable by mitigation or compensation measures.	
	Transportation (Section 6.2.1.8)	Representative corridor studies indicate that access roads from existing local highways and railroads to the site are possible to construct without conflict with federally dedicated lands (10 CFR 960.5-2-5 [d][2] and [3]), and with available technology, both for the roads and transport components. Transportation risks and costs are higher than at other salt sites. The site is not located in proximity to regional highways and mainline railroads that provide access to the national transportation system. Terrain in the area is rugged and existing local highways have steep grades and land-slide potential. A crossing of the Colorado River is necessary to provide rail access. The System Guideline transportation requirements defined in 10 CFR 960.5-1(a)(2) can nominally be met.	

With the exception of meteorological conditions, site characteristics pertinent to preclosure radiological safety are favorable. From an integrated system viewpoint, meteorological dispersion conditions that could be poor at times are not likely to prevent compliance with the radiation protection requirements. Radioactive releases from a repository are predicted to be very small and are expected to more than compensate for the less than favorable meteorological dispersion conditions. Modeling results (Section 6.4.1) indicate that no member of the public is likely to receive an annual whole-body dose greater than 1.3 millirem during the construction period, or greater than 1.8 millirem in any year during the operational period. Comparing these values with regulatory limits (EPA, 1982a, 40 CFR Part 191) of 25 millirem per year whole body or to approximately 139 millirem per year from natural background, it appears that a repository can be located and operated at the Davis Canyon site with insignificant radiological exposure risks to the public.

Results of analyses should be viewed in the context of assumptions and uncertainties set for the above. Additional detailed assumptions are described in Waite et al. (1985, BMI/ONWI-541, Rev. 1). The effect of these assumptions is to predict what is believed to represent upper bounds for radiological exposures during the preclosure period.

6.2.2.1.4 Conclusion for Qualifying Condition. The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.2.2.2 Environment, Socioeconomics, and Transportation, Guideline 10 CFR 960.5(a)(2)

Ranked second in importance in the preclosure System Guideline is environment, socioeconomics, and transportation (10 CFR 960.5-1[a][2]). In the final guidelines, the statement of this guideline was editorially revised for simplicity and clarity. The pertinent system elements will, in general, consist of (1) the people who may be affected, including their lifestyles, sources of income, social and aesthetic values, and community services; (2) the air, land, water, plants, animals, and cultural resources in the areas potentially affected by such activities; (3) the transportation infrastructure; and (4) the potential mitigating measures that can be used to achieve compliance with this guideline.

6.2.2.2.1 System Guideline Requirements. Part (2) of the preclosure System Guideline 10 CFR 960.5-1(a) defines the requirements for Environment, Socioeconomic, and Transportation as follows:

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

6.2.2.2.2 Evaluation Process. The type and nature of activities expected during repository siting, construction, operation, and decommissioning were examined for potential effects on the quality of the environment and the socioeconomic welfare of communities that might be most affected. Such activities included those required to emplace the facility at the site and to provide transportation and utility corridors.

Environmental implications of these activities were examined with respect to the projected ability to comply with applicable Federal and State statutes regulating waste disposal, land use, air quality, water quality, ecological resources, noise, historic and cultural resources, and radiological protection.

Radiological hazards due only to transportation of wastes are evaluated under this System Guideline. Radiological hazards from construction, operation, and decommissioning of the repository were considered under the preclosure radiological safety guideline (Section 6.2.2.1).

In addition, the effects that physical and human resources needed for project development might have on social and economic characteristics of potentially affected communities were examined. This included estimates of work-force requirements, direct and indirect in-migration, and commensurate needs for expanded community services and facilities.

Areas of potentially significant impact were then identified and the potential for implementing measures to mitigate those impacts was assessed.

Relevant Data. Descriptive material pertaining to this System Guideline can be found in sections as follows:

- Environment (Sections 3.2.3.3, 4.2.1, 5.2, 5.3.2, 6.2.1.6)
- Socioeconomics (Sections 3.6, 4.2.2, 5.4, 6.2.1.7)
- Transportation (Sections 3.5, 4.2.1.10, 5.3.1, 6.2.1.8).

Assumptions and Data Uncertainty. The assumptions and uncertainties associated with this System Guideline analysis are reflected in the assumption and data uncertainties section of each of the Technical Guidelines that make up the System Guideline (Environmental Quality, Socioeconomics, Transportation). The assumptions particularly pertinent to this System Guideline analysis include the following:

1. Impacts of actual repository access routes will be similar to those calculated for the alternative routes.

2. Projections of water availability for repository operations are reasonable.

3. Site-specific surveys will confirm that no threatened or endangered species or significant cultural resources will be significantly impacted.

4. In-migration of repository workers will be similar to actual in-migration at other large-scale energy projects.

5. Existing shaft sealing technology is sufficient to provide protection of the overlying aquifers.

6. Offsite disposal of salt is a viable option. Salt encrustation provides the predicted stabilization of the onsite storage pile.

7. Fugitive dust emission factors based on limited offsite measurements, where soil characteristics such as silt and moisture content are different from those existing at the site, are suitable for modeling TSP impacts. Offsite meteorological data from Salt Wash Tower are reasonably representative of the site.

8. Sound emission levels are accurate to ±5 dB. Unfavorable wind and temperature gradient effects, which would increase noise propagation toward the park, would be an infrequent occurrence.

6.2.2.2.3 Analysis. Impacts of repository-related activities at the Davis Canyon site with respect to the environment, socioeconomics, and transportation were analyzed in Chapters 4 and 5. Site conditions were compared with the Technical Guidelines (Sections 6.2.1.6, 6.2.1.7, and 6.2.1.8).

These analyses showed that the site conditions are such that most substantial Federal and federally mandated State land, water, and natural resources environmental protection requirements are likely to be met, but not necessarily within time constraints.

Environmental concerns addressed in the impact assessments (Chapters 4 and 5) included consideration of the effects of repository and related transportation and utility corridor development and operations on the following:

- Air quality
- Existing noise levels
- Water quality/availability
- Cultural resources
- Biota

- Land use
- Visual aesthetics.

Assessments also address social and economic impacts to communities resulting from population in-migration into a rural area. These impacts relate primarily to expanded service and facility requirements needed for increased populations, the costs of providing these infrastructure needs, and the potential social changes that might result.

The principal results of these environmental and socioeconomic impact assessments are summarized in Table 6-2. Particularly noteworthy results are discussed here.

Air Quality. The area in proximity to the site will experience an increase in suspended particulate and gaseous emissions during siting, construction, and operation. However, modeling results show that total suspended particulate (TSP) and nitrogen dioxide (NO_2) concentrations during all phases would be below National Ambient Air Quality Standards (40 CFR Part 50) (NAAQS). Stationary source emissions are below the level that triggers PSD requirements.

The visibility analyses utilize standard EPA visibility methodologies and find that the plume-contrast index is less than the threshold value for visibility impairment.

Except possibly for brief periods each day during repository construction, construction lighting may have an impact on night-sky brightness (skyglow) in the vicinity of the site.

Noise. Clearing, construction, and operation activities will cause an increase in ambient noise levels near the site. This increase in noise levels may be heard within Canyonlands National Park. The DOE believes that the noise impacts are acceptable because noise in the park will be limited to blasting noise audible to small areas at the eastern park boundary for only short durations during exploratory shaft, repository shaft, and railroad constructions.

Water Quality. Construction of shafts to the underground facility will require penetration of aquifers. Engineering safeguards to prevent contamination of this water source are a recognized necessity. Existing technology appears able to provide protection of these aquifers. Some local and temporary increases in sediment load in surface water will occur, but these increases will have only a minor impact on water quality.

Temporary storage of mined salt poses the need to minimize dissolution during the storage period and prevention of runoff and penetration to ground water. Practical engineering measures such as double-lined retention ponds should prevent contamination of surface water and ground water.

Water Resources. The site is located in an area of low water availability as both ground-water and surface-water resources are limited. The DOE has held preliminary discussions with local water conservation districts, and plans to purchase water from existing allotments of local municipalities.

Cultural Resources. It is felt that direct impacts on cultural resources during siting and construction can be mitigated. Residual indirect impacts will not result in a loss of significant amounts of cultural resource information.

Land Use. The area in which the site is located is primarily Bureau of Land Management (BLM) land. This land is used primarily for grazing, agricultural, and recreational activities which will be replaced by site characterization or repository activities. If the site is selected for a repository, DOE will permanently withdraw the land from the BLM.

Grazing will be affected by land withdrawal and possibly by access and utility corridors traversing current grazing lands. Grazing patterns and livestock management could be disrupted. Cattle crossings may be provided for, as appropriate. Total removal of the entire 2,333 hectares (5,760 acres) from grazing will comprise only 2.5 percent of the BLM Indian Creek grazing allotment.

Salt-handling control measures will be used to minimize the deposition of wind-blown salt on adjacent lands. Based on the low predicted deposition sites, no significant effects on land (rangeland) productivity are anticipated.

The site will not intrude on nearby dedicated lands. Ease of transportation access to Newspaper Rock State Historical Monument and Canyonlands National Park will be temporarily affected.

Biota. The existing data base indicates that no unique aquatic or terrestrial habitat is likely to be significantly affected by the repository.

Visual Aesthetics. The overall visual impacts of the repository will not be significant away from the immediate vicinity of the proposed repository, except along Utah 211, and from the Davis Canyon Jeep Trail. The surface facilities will not be visible from any scenic viewpoints or key observation points within Canyonlands National Park. The proposed facilities in Davis Canyon will, however, cause a significant adverse visual impact as viewed from the upper reaches of Davis Canyon within the park. These areas are not regarded as key observation points, are relatively inaccessible, and receive a small number of visitors. Each of the four alternative rail corridors create significant visual contrast impacts from two to three key observation points in the area; none of these is inside the park.

Cumulative Environmental Impacts to Canyonlands National Park. A summary of these environmental impacts to Canyonlands National Park was presented in Section 6.2.1.6. It was determined that potential impacts on the park during repository site characterization include shared traffic on Utah 211 (during site characterization), increased particulates and noise at the edge of the park, visibility of the site from Davis Canyon at the park boundary, night sky brightness, and the potential of nearby industrial development. The impact of episodic noise intrusion on solitude in the park would be significant, but of short duration over several years. During repository operations, all impacts mentioned above will be eliminated or reduced in those sections of the park designated for scenic, cultural, or solitude enjoyment purposes.

Socioeconomics. Available labor supplies within commuting distance are expected to be insufficient to meet requirements for repository-related activities. The projected number of persons (workers and families) expected to in-migrate into the area during peak employment is significant. This will result in significant population increases in the rural communities of Monticello, Blanding, and Moab. Job-training programs could provide increased opportunities for local employment, thus reducing the number of persons who might in-migrate. In addition, training for those employed during construction for longer-term operation employment could mitigate impacts by stabilizing the construction and operation-phase forces.

The population increase will require additional community services and facilities. The need for expanded community services and facilities could result in financial burdens to host communities as increased revenues from project and worker expenditures may not immediately be available to finance these capital expenditures.

The increased demand for labor could reduce local unemployment but also cause competition and decreases in labor available for other sectors of the economy. Advance community development planning and financial and technical assistance can lessen the impacts on affected communities. Increased tax revenues and business activity will contribute to mitigation in the long term.

Significant population increases will also cause social changes within communities. Planning for additional protective, social, and cultural services can mitigate these changes.

Transportation. Some temporary disruption in existing vehicular traffic flow can be expected, and some localized inconveniences experienced, as the construction of new transportation corridors and upgrading of others occurs. Depending on the alternative road and railroad routes selected for the repository and the time of year, some threatened and endangered species or their preferred habitats may be affected.

Radiological risks due to transportation of waste appear to be small. Estimates indicate that the maximally exposed individual could receive up to 3 percent of the normal background radiation.

The potential exists to provide new highway and rail routes that will not disrupt local cities and towns.

6.2.2.2.4 Conclusion for Qualifying Condition. The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

Table 6-8 summarizes the evaluations and the findings for preclosure System Guidelines not requiring site characterization.

6.2.3 Conclusion for the Qualifying Condition Regarding Suitability of the Site for Development as a Repository Under Guidelines not Requiring Site Characterization

On the basis of the findings stated in the above discussion of individual guidelines not requiring site characterization and made in accordance with Appendix III of the siting guidelines, it is concluded that the evidence does not support a finding that the site is disqualified, and does not support a finding that the site is not likely to meet the qualifying conditions. Therefore, it is concluded that there is no reason to believe that the site is not suitable for site characterization for selection of the first repository site.

6.3 SUITABILITY OF THE DAVIS CANYON SITE FOR SITE CHARACTERIZATION: EVALUATION AGAINST GUIDELINES THAT DO REQUIRE SITE CHARACTERIZATION

The purpose of this section is to meet the requirements of Section 112 (b)(1)(E)(i) of the NWPA by evaluating the site against these guidelines that require site characterization.

From the 10 CFR Part 960 definition of site characterization, the factors or information needs requiring site characterization have been specified. The corresponding Technical Guidelines that address these factors are as follows:

- Postclosure Technical Guidelines
  - 10 CFR 960.4-2-1 Geohydrology
  - 10 CFR 960.4-2-2 Geochemistry
  - 10 CFR 960.4-2-3 Rock Characteristics
  - 10 CFR 960.4-2-4 Climatic Changes
  - 10 CFR 960.4-2-5 Erosion
  - 10 CFR 960.4-2-6 Dissolution
  - 10 CFR 960.4-2-7 Tectonics
  - 10 CFR 960.4-2-8-1 Human Interference and Natural Resources

- Preclosure Technical Guidelines
  - 10 CFR 960.5-2-8 Surface Characteristics
  - 10 CFR 960.5-2-9 Rock Characteristics
  - 10 CFR 960.5-2-10 Hydrology
  - 10 CFR 960.5-2-11 Tectonics.

The evaluation of the postclosure Technical Guidelines is addressed in Section 6.3.1. The preclosure Technical Guidelines are evaluated in Section 6.3.3. The following sections address these Technical Guidelines using currently available information and assumptions inferred from the technical data base. Compliance of the site with the intent of these guidelines can only be determined adequately with site characterization.

Section 6.3.2 evaluates the Davis Canyon site with regard to the postclosure System Guideline. The System Guideline allows comparative evaluations of the sites in terms of the capabilities of the natural barriers for waste isolation and identifies innate deficiencies that could jeopardize compliance with the guidelines. These comparisons are based on the technical guidelines under the preclosure and postclosure guidelines.

6.3.1 Postclosure Technical Guidelines, 10 CFR 960.4-2

The guidelines in this section specify factors to be considered in evaluating and comparing sites on the basis of expected repository performance. They refer specifically to those characteristics and processes at or near the site that will affect the expected performance of the repository.

6.3.1.1 Geohydrology, Guideline 10 CFR 960.4-2-1

The geohydrologic Technical Guideline is focused on the past, present, and future characteristics of the geohydrologic setting of a site and their potential effects on the waste-isolation capability of a site. The most likely mechanism for the release of radionuclides from a repository to the accessible environment is transport by ground water. For this reason the geohydrologic conditions at a site must be evaluated on the basis of current understanding of the geohydrologic setting and potential future changes.

This guideline includes a qualifying condition, five favorable conditions, and three potentially adverse conditions for analysis. It also has one disqualifying condition.

6.3.1.1.1 Statement of Qualifying Condition.

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

Evaluation Process. Compliance with the requirements referenced in the qualifying condition is addressed by performance assessment analyses described in Sections 6.4.2.4 and 6.4.2.3.5. The geohydrologic system is evaluated with regard to compatibility with waste isolation, especially ground-water travel time from the repository to the accessible environment. Further evaluations address the confidence with which existing hydrologic conditions can be modeled and the potential for expected changes in the present hydrologic system.

The modeling used for evaluation of the site for compliance with this qualifying condition is based on data obtained from: (1) review of the literature, (2) analysis of water well and petroleum exploration well records, and (3) drill-stem testing and laboratory testing conducted for the Office of Civilian Radioactive Waste Management exploration program. These data are used to describe the ground-water flow systems and the rock parameters. These parameters include permeability, primary effective porosity, and formation fluid pressures in order to determine the paths, amounts, and times for ground-water travel and associated uncertainty. The evaluations and findings are summarized in a table at the end of Section 6.3.1.

Relevant Data. Description of the regional geology and geohydrology in the vicinity of the Davis Canyon site is presented in Chapter 3. These descriptions are based on numerous published reports of geologic and geohydrologic investigations, and include the following:

- Regional Geology (Section 3.2.1)
- Paleoclimate (Section 3.2.2.3)
- Stratigraphy (Section 3.2.3)
- Structure and Tectonics (Section 3.2.5)

- Hydrology with lithologic descriptions of geohydrologic units and hydraulic head analyses (Section 3.3.2.1)

- Ground Water (Section 3.3.2.2).

The geohydrologic setting of the site is described in Section 3.3.2. Detailed lithologic logs of core from the Gibson Dome No. 1 (GD-1) borehole, and geologic correlation of a suite of detailed geophysical logs from GD-1 with surrounding boreholes, indicate that thick, extensive halite beds are present at the site (Figure 3-15). No salt dissolution has been detected within 10 kilometers (6 miles) of the site (Section 6.3.1.6).

The continuous cores from GD-1 display the original lithologies of the salt section (Section 3.3.2.1) indicating little or no ground-water movement through the unit since deposition. Lab tests on core from GD-1 (Thackston et al., 1984, ONWI-491, Table 3-8) show effective primary porosities of less than 0.5 percent, and hydraulic conductivities of less than 1×10^{-10} centimeters per second (3.2×10^{-12} feet per second) for Salt Cycle 6, supporting the general conclusions reported by the National Bureau of Standards (Gevantman, 1981, p. 29-31) that the permeability and effective porosity of halite are approximately zero, after diagenesis and burial at depths of more than 12 meters (39 feet). Borehole hydraulic tests of strata surrounding the potential host rock in GD-1 also revealed low values of hydraulic conductivity (Tables 3-23 and Figures 3-56 and 3-58). All hydrologic test data obtained from GD-1 are discussed in detail in Thackston et al. (1984, ONWI-491).

In addition to borehole tests in GD-1, available data from wells and springs in the candidate area have been obtained, analyzed, and tabulated (Table 3-24, Figure 3-53 and 3-54). Ground-water flow directions and hydraulic gradients have been estimated from ground-water level data, where available (Table 3-24, Figures 3-62 and 3-63).

Estimated hydraulic heads (potentiometric levels) and hydraulic conductivities for each unit are summarized in Section 3.3.2.1; approximate salinities of the ground water within each unit, based on available data, are summarized on Figures 3-55 and 3-57.

Assumptions and Data Uncertainty. A principal assumption is that the geohydrologic system, as it is described in the sections cited under relevant data, is reflective of the natural system. The uncertainty associated with hydrologic parameters used in the following evaluation is described in Section 6.4.2.3.5. A stochastic ground-water flow model (Section 6.4.2.3.5) is used to predict ground-water travel time and is one that in particular addresses the uncertainty associated with the existing data. The model is briefly described below.

Salt permeability is a function of the permeating fluid, confining pressure, and the type and amount of impurities found in the salt deposits. With different permeants and confining pressures, the range of salt permeability has been observed to be from 10^{-22} to 10^{-12} square meter (10^{-7} to 10^{3} millidarcy) (Bateman, 1985). The higher range of salt permeabilities was derived from tests using permeants such as nitrogen, air mixtures, freon, gasoline, and diesel oil. Brine is the natural permeant of concern for a salt repository assessment, and for which zero to very low permeabilities have been reported. With brine as permeant, the low permeabilties are due to salt recrystallization and redeposition of impurities (Aufricht and Howard, 1971, p. 736). The containment of brine pockets provides the indirect evidence that in situ rock salts are almost impermeable (Baar, 1977). These internal water reservoirs are hydraulically isolated (MSHA, 1978; Knauth, 1982).

In general, the laboratory measured permeabilities are also higher than the in situ permeability measurements. Laboratory specimens generally are disturbed and may exhibit stress-release fractures (Gloyna and Reynolds, 1961, p. 3921). In situ permeability tests may not always reflect undisturbed in situ conditions because of disturbances from drilling or mining activities. In drill holes and mines the stress release fractures and salt creep resulting from in situ stress conditions may cause overestimation of the disturbed-salt permeability by many orders of magnitude (Bateman, 1985, p. 19). Some of the higher in situ permeability measuremens when compared to the laboratory data may result from localized

effects or inclusions of anhydrite and shale layers in long test intervals (Tien et al., 1982; Stormont, 1984, SAND84-1057). Recent salt permeability tests show lower permeability values than older tests (Sutherland and Cave, 1978; Blankenship and Stickney, 1983, ONWI-190[3]) because of improvements in test sample collection, handling, testing techniques, and higher sensitivity of test instruments.

The salt permeability range of 10^{-7} to 10^{-2} millidarcy is used in the analysis of groundwater travel time estimates. This range covers the maximum observed values under in situ confining pressures and with brine as a fluid permenat. The permeability ranges utilized for other layers are based on available regional permeability values (measured or interpreted) for the Paradox Basin. For those layers lacking site-specific data, representative values of a generic rock type are used. The permeabilities in all layers are assumed to be log-normally distributed.

Results of drill-stem tests (DSTs) conducted in petroleum exploration boreholes are a principal source of data in the analyses. The calculation of permeability and potentiometric level values from these tests performed to evaluate compliance with the qualifying condition have considerable uncertainty. The testing technique was developed to indicate the presence or absence of hydrocarbons, and approximate reservoir pressures. As a result, the numerical values obtained for potentiometric levels from the test records may be approximately 61 meters (200 feet) above or below actual values. The accuracy and precision of permeability measurements are also difficult to quantify. In general, the lowest measureable permeability, using the conventional DST technique, is approximately 1 millidarcy (1×10^{-11} square centimeter). Uncertainty in DST values arises from a combination of the following factors: pressure gage error, unknown variations in specific gravity of the borehole fluid column, test tool leakage, and effects of drilling on the hydrologic characteristics of the formation tested. Therefore, all petroleum DST results, although potentially useful, should be viewed as approximations.

Borehole hydraulic tests performed at GD-1 provide definitive data for that location. These data indicate that great thicknesses (550 meters [1,800 feet]) of relatively impermeable, fine-grained strata are present above and below the proposed repository horizon. However, exact numerical values of hydraulic conductivity obtained in the short-term borehole hydraulic tests at GD-1 are still somewhat uncertain, particularly for values less than 1×10^{-7} centimeters per second (3.2×10^{-9} feet per second). Because most of the tests were only 1 to 3 days long, the test results represent the characteristics of only a relatively small volume of rock near the borehole wall, and therefore, may not be truly representative of "average" formation conditions (i.e., exact numerical mean values for a larger area or fracture flow). To some degree this limitation applies to all borehole hydraulic tests.

To address uncertainties in hydrogeologic parameters, a range of values, based on observed and reported information, was considered. Parametric distributions (as summarized below) have been sampled using the Latin Hypercube sampling technique for 1,000 realizations to estimate travel times from the disturbed zone to the accessible environment.

The pressures utilized in evaluating the vertical hydraulic gradients are based on observations made at Gibson Dome No. 1 by Thackston et al. (1984, ONWI-491). The variation in travel paths is dependent on observed pressures in the lower portions of the Honaker Trail and in the interbeds of the Paradox Formation. The observed variability produces both downward and upward local hydraulic gradients across the host salt. For these analyses, both possibilities were used.

The total dissolved solids content values for evaporites, interbeds, and deep-brine aquifers were varied throughout the analyses, as described in Section 6.4.2.3.5.

The horizontal hydraulic gradients utilized in the analyses is considered to vary for each layer as described in Section 6.4.2.3.5.

To address a low probability related to undetected fractured zones (ONWI, 1985) groundwater travel time estimates consider a distribution of minimum distances from the repository to surface faults. No evidence has been found to support the correlation of these surface

features with a zone of increased fracturing or permeability within brittle beds at depth (ONWI, 1985). The probability of ground-water paths intersecting a fracture zone is generated by randomly locating the centroid of the repository within the spatial distribution of surface lineaments. The effective porosity of the fracture zone was decreased by two orders of magnitude resulting in lower travel times. In the fracture zones water is assumed to move 100 times faster than in the matrix. Calculations representing fracture flow produce the lower end of travel times given in Section 6.4.2.3.5.

For the pre-waste-emplacement ground-water travel time analyses, the following two assumptions were made: (1) salt is a porous medium, and (2) the disturbed zone extends upward to the base of the interbed overlying Cycle 6 and downward to the top of the interbed underlying Cycle 6. Travel time through the host salt between the disturbed zone and interbed is not added to the total travel time to the accessible environment.

For the analysis of ground-water travel time, only porous media flow is considered. A less likely flow mechanism than porous flow is flow through fracture-controlled pathways. Extensive zones of such fractures have not been identified at the site, however, an analysis was made to investigate their possible effects (Section 6.4.2.3.5). The travel times generated from this analysis are not used in the postclosure geohydrological guidelines evaluation. The distances of fracture zones from the disturbed zone were treated probabilistically such that fractures could occur at the disturbed zone or as much as 5 kilometers (3 miles) distant. The fracture zone was always considered to be parallel to the direction of flow and to have aquifer parameters so as to increase ground-water velocities 100 times over those of nonfractured beds.

The uncertainty in travel times due to uncertainties in hydrologic parameters is described in Section 6.4.2.3.5 along with travel time calculations. From these analyses and discussions of uncertainties it is determined that the qualifying condition is met.

Analysis. The greatest potential for transporting radionuclides from the repository horizon to the accessible environment is though ground-water flow. A major reason for selecting rock salt as a medium for disposing of radioactive wastes is the absence or extremely low rate of ground-water flow in salt. The brine that normally occurs within salt deposits is in the form of intracrystalline inclusions, intergranular brine, and brine associated with interbed impurities and chemically bound water (Section 3.2.7). Migration of these different forms of brine occurs by various mechanisms. The intracrystalline inclusions tend to migrate under the influence of temperature gradients, the intergranular and interbed brines tend to move in response to pressure gradients (Jenks and Claiborne, 1981, ORNL-5818; Olander, 1982). The temperatures in a salt repository are not expected to reach levels high enough to mobilize chemically bound water (Shefelbine, 1982, SAND82-0152; Section 6.3.1.2).

As long as the radioactive waste is significantly hotter than the ambient salt temperature, the intercrystalline brines will tend to migrate towards the waste package under the influence of the temperature of the waste package wall. If the package fails, the radionuclide release rates will be controlled by radionuclide solubilities. When the radioactive waste has cooled to near the ambient salt temperature, the brine accumulated around the waste package will migrate away from the package by a diffusion-like mechanism. Calculations of radionuclide transport using this mechanism indicate that the EPA standards for releases to the accessible environment (40 CFR Part 141) are not exceeded. In fact, calculations show that radionuclide transport time for 10 meters (33 feet) exceeds 100,000 years (Section 6.4.2.4.2).

Analyses of 1,000 realizations of hydrogeologic parameter distribution using the stochastic ground-water model (Section 6.4.2.3.5), indicate a range of possible travel times and various travel paths from the disturbed zone to the accessible environment.

EPA regulatory requirements (40 CFR Part 191) limit the controlled area to a maximum area of 100 square kilometers (39 square miles) and a maximum distance of 5 kilometers (3 miles) from the repository. Site characterization will identify the distance from the repository to the controlled area boundary (the accessible environment). Thus, on the basis of information

available at that time, the size and shape of the controlled area could be adjusted to meet regulatory requirements.

Analyses described in Section 6.4.2.3.5 assess ground-water travel time in increments of from 1 to 5 kilometers (0.6 to 3 miles). These sensitivity analyses are primarily used to provide understanding of probabilities of ground-water travel times with variable distances to the controlled area boundary. The distance from the underground workings to the boundary of the proposed controlled area, as presently described, is approximately 1 kilometer (0.6 mile) in the downgradient dirction (Figure 3-2). The travel times used for analyzing the geohydrology postclosure guidelines are based on a travel distance of 1 kilometer (0.6 mile) and are reported for calculations using Ismay pressures because these pressures yield the most conservative travel times.

The variation in travel paths is a function of the horizontal and vertical permeability of individual lithologic layers and the horizontal and vertical gradient within these layers. The pressures used to calculate vertical hydraulic gradients for ground-water travel time calculation are based on observations at GD-1 (Thackston et al., 1984, ONWI-491) (Table 3-23). Observed pressures in the lower portions of the Honaker Trail and in the interbeds of the Paradox Formation are erratic. The observed variability could indicate either downward or upward hydraulic gradients across the host salt. Ground-water travel time analyses (Section 6.4.2.3.5) considered both possibilities (Table 6-9). When downward porous flow is considered (Ismay pressure), most particle paths enter the accessible environment via the interbed beneath Salt Cycle 6 and travel time to the accessible environment has median and mean values of 2.4×10^5 years and 4.1×10^5 years, respectively. For the distribution of calculated travel times the median is a measure of central tendency and is more conservative than the mean. Many of the conservatisms used in these analyses tend to broaden the travel time distribution and to produce some travel time calculations of less than 10,000 years. Even with this conservative analysis 955 of the 1,000 realizations produced travel times of 10,000 years or greater.

The following observation also supports the likelihood of large travel times. The logs from the GD-1 core and other boreholes in the site vicinity indicate no evidence of dissolution in the site vicinity. The absence of dissolution indicates that ground-water circulation systems have not been operating in the host rock in the past. Therefore, the expected condition is that radionuclides would be transported through the host rock by the diffusion-like process discussed in Section 6.4.2.4.2 rather than through ground-water flow. Analyses considering diffusion indicate that radionuclides would travel less than 10 meters (33 feet) through salt in 100,000 years. Salt Cycle 6 is approximately 61 meters (200 feet) thick at the site. Therefore, it is expected that the salt cycle will contain the waste well beyond the first 100,000 years.

6.3.1.1.2 Analysis of Favorable Conditions.

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

Evaluation. The geologic evidence shows that essentially no ground water has flowed into or through the potential host rock in the vicinity of the site since early diagenesis of the salt deposits. It can be inferred on the basis of this observation that ground-water travel times within the host rock could be infinitely long. However, laboratory tests (Gloyna and Reynolds, 1961; Aufricht and Howard, 1961; Isherwood, 1981, Vol. 1, p. 194) have indicated that some extremely small movement of fluid may be occurring in core samples of salt during long-term laboratory tests. Sampling disturbance is certainly a factor and cannot be resolved until in situ measurements are possible.

The DOE siting guidelines (10 CFR 960.2) define the accessible environment as the region outside of the controlled area. The controlled area and its relation to the repository are shown in Figure 3-2. The lateral extent of the disturbed zone is discussed in Appendix 6-A

Table 6-9. Particle Exit Layer Distributions for 1,000 Realizations[a] of Davis Canyon Local Ground-Water System, 5 Km Accessible Environment, Including Fracture-Controlled Pathways[a]

	Ismay Pressure 2.0 km Repository Radius	Honaker Trail Pressure 2.0 km Repository Radius
Elephant Canyon		
Honaker Trail (upper)		
Honaker Trail sandstone		
Honaker Trail (lower)		.341
Ismay		.086
Paradox Salt Cycle 5		
Paradox Salt Cycle 5 interbed		.573
Paradox Salt Cycle 6 interbed	.374	
Paradox Salt Cycle 7		
Paradox Salt Cycle 7 interbed	.074	
Paradox Salt Cycle 8 interbed	.127	
Paradox Salt Cycle 9		
Paradox Salt Cycle 9 interbed	.097	
Paradox Salt Cycle 10	.001	
Paradox Salt Cycle 10 interbed	.109	
Paradox Salt Cycles 13-26	.003	
Pinkerton Trail	.104	
Molas	.043	
Leadville Limestone	.068	
Total	1.000	1.000

(a) Representations of ground-water system by selecting combinations of geohydrologic parameters.

and is estimated to be less than 15 meters (50 feet). The shortest horizontal distance from the disturbed zone to the accessible environment is seen to be approximately 1 kilometer (0.6 mile). In the vertical dimension, the disturbed zone is projected to extend upward to the base of the interbed above Cycle 6 and downward to the top of the interbed below Cycle 6. This assumption has been made because of the combined uncertainties in the extent of the disturbed zone, and the exact vertical placement of the repository horizon.

Likely flow paths are considered those described by porous flow through layered unfractured strata. Unlikely flow paths are those which might be created by fracture zones, although there is no evidence that such zones exist.

Flow calculations using a stochastic ground-water flow model (Section 6.4.2.3.5) incorporate the possibility of either upward or downward flow from the host salt bed. The model incorporates a wide-range of uncertainties in aquifer parameters and hydraulic gradients (based on field and laboratory data) assuming a porous media flow mechanism. Flow through the host salt bed was not considered in these calculations, which were made as if the flow initiated in a water-bearing bed above or below the host salt bed. The median and mean calculated travel times to the accessible environment at a distance of 1 kilometer (0.6 mile) are 2.4×10^5 years and 4.1×10^5 years, respectively, using Ismay pressures (most conservative). Travel times are equal to or exceed 10,000 years for 955 out of the 1,000 realizations (a probability of 0.955 that the 10,000 year travel time condition is met).

The stochastic approach taken in Section 6.4.2.3.5 to evaluate ground-water travel time produces a distribution of possible travel times. The distribution results from natural variability and uncertainty in the hydrologic perameters. Conservative assumptions built into the flow model serve to shift the distribution to lower travel times. The extreme upper and lower portions of the travel-time distribution are characteristic of travel times along unlikely paths of radionuclide travel, and therefore inappropriate for evaluating this favorable condition. The DOE considers this judgement to be consistent with the NRC staff position regarding the ground-water travel-time requirement in 10 CFR Part 60 (Browning, 1985).

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

For the interim, a measure of central value of the travel-time distribution is considered appropriate for evaluating the proposed site against the favorable condition. The mean is a mathematical approximation of the expected travel time (Davenport, 1970). The median is also a measure of central value and, in this case, a more conservative value. For this reason, median travel time values, as well as mean values, are used in evaluating this favorable condition. In each set of conservative calculations of ground-water travel time (Section 6.4.2.3.5), both the mean and median travel times exceed 10,000 years. Therefore, for purposes of this evaluation the evidence indicates the favorable condition is present.

The evidence indicates that the favorable condition is present.

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

Evaluation. The hydrologic processes that may affect the capability of the host rock to isolate the radioactive waste are precipitation, evapotranspiration, runoff, ground-water recharge, and discharge. The nature and rates of these hydrologic processes will be primarily influenced by climate during the next 100,000 years. Climatic changes during the Pleistocene are discussed in Sections 3.2.2.3 and 6.3.1.4.

The effect of climatic change on the rate of ground-water flow through the repository host rock was determined to be negligible, because of the lack of evidence that ground-water flow parameters have changed during the Quaternary. A change of any significance during previous glacial cycles would have resulted in indications that dissolution of the evaporitic strata, or at least some evidence of ground-water flow through the evaporites, had occurred. (Sections 3.3.2.2 and 6.3.1.6).

The effect of climatic change on porosity and permeability of the rocks above the salt also seems to be small to almost negligible, based on petrographic examination of GD-1 core, and an evaluation of diagenetic products (McCulley et al., 1984, p. 24). Essentially no data are available on change in hydraulic gradient caused by past climatic variations. However, by making the simple worst case assumption that future precipitation rates increase to the point that the water table reaches ground surface in the Abajo Mountains, the resultant hydraulic gradient between the Mountains and the Colorado River is not significantly greater than the apparent maximum hydraulic gradient estimated from GD-1 hydrologic tests.

The evidence indicates that the favorable condition is present.

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

Evaluation. The relative simplicity of stratigraphic, structural, and hydrogeologic features in the site vicinity makes the task of characterizing and numerically modeling the ground-water system appear to be relatively straightforward. Preliminary numerical models representing the primary porosity portion of the bedrock have been successfully applied to the region surrounding the site (INTERA, 1984, BMI/OWNI-547; 1985, BMI/ONWI-553; Dunbar and Thackston, 1985, BMI/ONWI-571). However, to address the uncertainties in the hydrogeologic parameters, the range of each parameter and its distributions was considered as discussed in Sections 3.3.2.2 and 6.4.2.3.5.

The limited data base and the preliminary state of development of the models available at present limits their usefulness for site characterization. It is for this reason that the geohydrologic systems surrounding the site cannot be considered readily characterized and modeled at this time.

The evidence indicates that the favorable condition is not present.

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

(i) A host rock and immediately surrounding geohydrologic units with low hydraulic conductivities.

(ii) A downward or predominantly horizontal hydraulic gradient in the host rock and in the immediately surrounding geohydrologic units.

(iii) A low hydraulic gradient in and between the host rock and the immediately surrounding geohydrologic units.

(iv) High effective porosity together with low hydraulic conductivity in rock units along paths of likely radionuclide travel between the host rock and the accessible environment.

Evaluation. This condition has been evaluated as follows:

1. A low hydraulic conductivity is considered to be less than 10^{-6} centimeter per second. Hydraulic conductivity (permeability) of the host rock and surrounding units is discussed in Section 3.3.2. All available data suggest that the host rock and surrounding strata have low hydraulic conductivities. Subcondition (i) is present.

2. While the regional vertical gradient between the upper and lower hydrostratigraphic units is generally downward across the middle hydrostratigraphic units, the variable pressures observed at GD-1 (Thackston et al., 1984, ONWI-491; Table 3-23) indicate that locally upward or downward gradients may be present across individual salt beds within the Paradox Formation. The ground-water analyses considered these variations. Subcondition (ii) is not present.

3. No reliable potentiometric level measurements were obtained in the host rock, so the gradient between it and other units cannot be provided. Subcondition (iii) is not present.

4. Lab tests for GD-1 core (Table 3-23) show that effective primary porosity in the Elephant Canyon and Leadville Limestone are higher in general than in other stratigraphic units surrounding the host rock, but the hydraulic conductivities are not low. Subcondition (iv) is not present.

The favorable condition requires that at least one favorable subcondition be present. Subcondition (i) is present.

The evidence indicates that the favorable condition is present.

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

(i) A low and nearly constant degree of saturation in the host rock and in the immediately surrounding geohydrologic units.

(ii) A water table sufficiently below the underground facility such that the fully saturated voids continuous with the water table do not encounter the host rock.

(iii) A geohydrologic unit above the host rock that would divert the downward infiltration of water beyond the limits of the emplaced waste.

(iv) A host rock that provides for free drainage.

(v) A climatic regime in which the average annual historical precipitation is a small fraction of the average annual potential evapotranspiration.

Evaluation. This condition does not apply because the host horizon is below the water table.

The evidence indicates that the favorable condition is not applicable.

6.3.1.1.3 Analysis of Potentially Adverse Conditions.

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

Evaluation. Changes in the pre-waste-emplacement geohydrologic conditions as a result of natural phenomena are not expected (Section 6.3.1.1.3). Changes related to repository construction and heat generated by the emplaced waste (Section 6.4.2.3) are not considered in this evaluation.

The evidence indicates that the potentially adverse condition is not present.

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

Evaluation. No potential ground-water sources are reported or suspected along ground-water flow paths (Section 6.4.2.3.5) to the accessible environment because of the high salinity of the ground water in the Pennsylvanian and older formations, and the Honaker Trail (Figures 3-55 and 3-57). Additional information on water quality and water use can be found in Section 3.3.3.1.

The evidence indicates that the potentially adverse condition is not present.

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

Evaluation. Structural features such as faults, folds, dissolution zones, and brine pockets (Sections 3.2.5.1, 3.2.5.4, 3.2.5.6, and 3.2.7.2, respectively) are found within the geologic setting, which could contribute to the difficulty of characterizing the geohydrologic system. However, because of the distance of known features such as these from the site and their generally wide dispersion within the geologic setting, it is not certain to what degree they will add to the difficulty of characterizing or modeling the geohydrologic system.

The evidence indicates that the potentially adverse condition is present.

6.3.1.1.4 Analysis of Disqualifying Condition.

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

Evaluation. Pre-waste-emplacement ground-water travel time along any path of likely radionuclide travel from the disturbed zone to the accessible environment has been estimated to require much longer than 1,000 years (Sections 6.3.1.1.2 and 6.4.2.3.5). As summarized in Table 6-37, the probability of not meeting the 1,000 year travel time criteria, assuming porous flow, is less than 0.003.

The evidence does not support a finding that the site is disqualified (Level 1).

6.3.1.1.5 Conclusion for the Qualifying Condition.

The site is located such that the present and expected geohydrologic setting is compatible with waste containment and isolation. The ground-water travel time through the evaporite section and beyond has been conservatively estimated, and is expected to exceed the 10,000 year guideline requirement. Median and mean travel times using Ismay pressures were 2.4×10^5 years and 4.1×10^5 years, respectively, to the accessible environment set at a distance of approximately 1 kilometer (0.6 mile).

These conclusions regarding travel time indicate that the ground-water conditions at the site are compatible with waste isolation.

The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.3.1.2 Geochemistry, Guideline 10 CFR 960.4-2-2

The objective of the geochemistry Technical Guideline is to ensure that past, present, and expected geochemical characteristics of a site are compatible with waste containment and

the engineered-barrier systems. The guideline addresses two aspects of the geochemical environment: 1) the conditions that affect the release of radionuclides from the engineered-barrier system and 2) the conditions that affect the subsequent retardation of radionuclide migration in the geohydrologic system (e.g., conditions related to radionuclide precipitation or sorption and the formation of complexes or physical states that increase the mobility of radionuclides).

This guideline includes a qualifying condition, five favorable conditions, and three potentially adverse conditions for analysis. It does not have a disqualifying condition.

6.3.1.2.1 Statement of Qualifying Condition.

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

Evaluation Process. To determine whether the qualifying conditions with respect to the geochemical characteristics specified in 10 CFR 960.4-2-2 can be met, relevant data are summarized and evaluated. Evaluations are made regarding whether favorable, potentially adverse, and disqualifying conditions exist at the site. These conditions and findings are summarized in Table 6-10. Conclusions drawn with respect to qualification of the site for further consideration as a potential repository are presented along with a rationale for these conclusions. Cross referencing is provided to other sections of the report.

Chemical interactions expected in the host rock are (1) corrosion of the waste package either by brines presently included in the salt, or brine produced by entry of ground water into the repository; and (2) dissolution of radionuclides from the waste form. The geochemical process of interest outside the host rock is retardation. By this process the transport rate of some radionuclides will be reduced to less than the flow rate of the ground water.

Relevant Data. Geochemistry data relevant to this guideline are those that describe the host salt bed, adjacent strata, and the fluids present in both. Data obtained during pre-site-characterization studies and generic data are used in the following analyses. The mineralogy and chemical composition of salt and adjacent strata, chemical composition of water in the adjacent strata, and fluid inclusions within the salt are discussed in Section 3.2.7. Evidence for post-depositional salt dissolution is discussed in Sections 3.2.5.6 and 6.3.1.6. Laboratory corrosion test results for candidate waste package components are provided in Section 6.4.2.

Assumptions and Data Uncertainty. Site-specific geochemical information has not been obtained. However, it is assumed that the data from the GD-1 borehole located 5 kilometers (3 miles) northeast of the the Davis Canyon site will provide information representative of the site. For example, the thickness of Cycle 6 interval at the Davis Canyon site is not precisely known. Current estimates are based on its thickness at GD-1 and information from geophysical logs, which suggest that Cycle 6 becomes somewhat thinner at the proprosed site. The carnallite marker bed located in the upper portion of Cycle 6 at GD-1 is also presumed to be present at the proposed site, but site-specific data on its thickness and chemical and mineralogical composition are not currently available. Without site-specific chemical data, the brine content of Cycle 6 at the Davis Canyon site must be approximated based on data from GD-1. These approximations are based on deliberately over-estimated values of potential brine sources (Section 3.2.7.1), in order to avoid understating the potential for brine accumulation in the waste package environment. Site-specific brine chemisty and corrosion rate data based on Paradox brine compositions are also not available. Brine compositions are approximated by

Table 6-10. Postclosure Technical Guidelines Requiring Site Characterization, Davis Canyon Site

Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
Geohydrology	960.4-2-1	6.3.1.1		
(a) Qualifying Condition				
The present and expected geohydrologic setting of a site shall be compatible with waste containment and isolation. The geohydrologic setting, considering the characteristics of and the processes operating within the geologic setting, shall permit the compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered barrier system using reasonably available technology.			The site is expected to meet this condition because ground-water travel time to the accessible environment greatly exceeds the favorable condition of 10,000 years. This assessment is made using no adjustment for radionuclide retardation. The probability of travel times being less than 10,000 years is 0.214 (1,000 trials) at a distance of 1 kilometer. A median travel time value of 120,000 years was determined using Ismay pressures while combining fracture and porous flow.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
(b) Favorable Conditions				
(1) Site conditions such that the pre-waste-emplacement ground-water travel time along any path of likely radionuclide travel from the disturbed zone to the accessible environment would be more than 10,000 years.			Prewaste-emplacement ground-water travel time greatly exceeds 10,000 years. The probability of travel times being less than 10,000 years if 0.214 (1,000 trials) at a distance of 1 kilometer. A median travel time value of 120,000 years was determined using Ismay pressures while combining fracture and porous flow.	The evidence indicates that a favorable condition is present.
(2) The nature and rates of hydrologic processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years.			Reasonably foreseeable climatic changes are not anticipated to be different from those experienced in the past. These changes are not anticipated to have an effect on repository performance.	The evidence indicates that a favorable condition is present.
(3) Sites that have stratigraphic, structural, and hydrologic features such that the geohydrologic system can be readily characterized and modeled with reasonable certainty.			Preliminary state of information and models precludes finding this favorable condition present.	The evidence indicates that a favorable condition is not present.
(4) For disposal in the saturated zone, at least one of the following pre-waste-emplacement conditions exists:			Hydraulic conductivities for surrounding units are low.	The evidence indicates that a favorable condition is present.

Table 6-10. Postclosure Technical Guidelines Requiring Site Characterization, Davis Canyon Site
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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(i) A host rock and immediately surrounding geohydrologic units with low hydraulic conductivities.			Hydraulic conductivities of the salt and interbeds are low.	The evidence indicates that a favorable condition is present.
(ii) A downward or predominantly horizontal hydraulic gradient in the host rock and in the immediately surrounding geohydrologic units.			Upward gradients are possible at the repository horizon.	The evidence indicates that a favorable condition is not present.
(iii) A low hydraulic gradient in and between the host rock and the immediately surrounding geohydrologic units.			The gradient between the salt and the interbeds is not low.	The evidence indicates that a favorable condition is not present.
(iv) High effective porosity together with low hydraulic conductivity in rock units along paths of likely radionuclide travel between the host rock and the accessible environment.			High effective porosity is not expected in the interbeds.	The evidence indicates that a favorable condition is not present.
(5) For disposal in the unsaturated zone, at least one of the following pre-waste-emplacement conditions exist:			The proposed host rock is within saturated zone; therefore, the condition does not apply.	The condition is not applicable.
(i) A low and nearly constant degree of saturation in the host rock and in the immediately surrounding geohydrologic units.				
(ii) A water table sufficiently below the underground facility such that the capillary fringe does not encounter the host rock.				
(iii) A geohydrologic unit above the host rock that would divert the downward infiltration of water beyond the limits of the emplaced waste.				
(iv) A host rock that provides for free drainage.				
(v) A climatic regime in which the average annual historical precipitation is a small fraction of the average annual potential evapotranspiration.				

Table 6-10. Postclosure Technical Guidelines Requiring Site Characterization, Davis Canyon Site
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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(c) Potentially Adverse Conditions				
(1) Expected changes in geohydrologic conditions--such as changes in the hydraulic gradient, the effective porosity, and the ground-water flux through the host rock and the surrounding geohydrologic units--sufficient to significantly increase the transport of radionuclides to the accessible environment as compared with prewaste-emplacement conditions.			Expected changes will not significantly increase transport.	The evidence indicates that a potentially adverse condition is not present.
(2) The presence of ground-water sources, suitable for crop irrigation or human consumption without treatment, along ground-water flow paths from the host rock to the accessible environment.			As a result of high salinities measured in ground water along likely flow paths, water present is not suitable for use without treatment.	The evidence indicates that a potentially adverse condition is not present.
(3) The presence in the geologic setting of stratigraphic or structural features--such as dikes, sills, faults, shear zones, folds, dissolution effects, or brine pockets--if their presence could significantly contribute to the difficulty of characterizing or modeling the geohydrologic system.			Stratigraphic or structural features do occur within the geologic setting which could contribute to the difficulty of characterizing the geohydrologic system. However, because of their distance from the site and their widespread occurrence within the setting, it is not certain to what degree they will contribute to the difficulty of characterizing or modeling the system.	The evidence indicates that a potentially adverse condition is present.
(d) Disqualifying Condition				
A site shall be disqualified if the pre-waste-emplacement ground-water travel time from the disturbed zone to the accessible environment is expected to be less than 1,000 years along any pathway of likely and significant radionuclide travel.			Expected prewaste-emplacement ground-water travel times greatly exceed 1,000 years. The probability of travel times being less than 10,000 years is 0.214 (1,000 trials) at a distance of 1 kilometer. A median travel time value of 120,000 years was determined using Ismay pressures while combining fracture and porous flow.	The evidence does not support a finding that the site is disqualified (Level 1).

Table 6-10. Postclosure Technical Guidelines Requiring Site Characterization, Davis Canyon Site
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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
Geochemistry	960.4-2-2	6.3.1.2		
(a) Qualifying Condition				
The present and expected geochemical characteristics of a site shall be compatible with waste containment and isolation. Considering the likely chemical interactions among radionuclides, the host rock, and the ground water, the characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered barrier system using reasonably available technology.			Assessments of the geochemical environment and waste package corrosion show that the system will contain radionuclides for time periods in excess of the requirements under expected conditions.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
(b) Favorable Conditions				
(1) The nature and rates of the geochemical processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years.			Salt dissolution continuing at Quaternary rates is not expected to permit ground water to reach the repository for considerably longer than 10,000 years. The thermal alteration of carnallite and other evaporite minerals is not expected to adversely affect the ability of the repository to isolate wastes.	The evidence indicates that a favorable condition is present.
(2) Geochemical conditions that promote the precipitation, diffusion into the rock matrix, or sorption of radionuclides; inhibit the formation of particulates, colloids, inorganic complexes, or organic complexes that increase the mobility of radionuclides; or inhibit the transport of radionuclides by particulates, colloids, or complexes.			Reducing conditions will promote the precipitation of many redox-sensitive radionuclides; others may form insoluble sulfate or carbonate minerals. Radiocolloid formation is expected to be minimized by the destabilizing effects of brines. Deep basin brines contain low concentrations of low molecular weight organic acids, which are weak complexing agents. Radiolysis reactions may form additional organic species which are not expected to possess significant complexation characteristics.	The evidence indicates that a favorable condition is present.
(3) Mineral assemblages that when subjected to expected repository conditions, would remain unaltered or would alter to mineral assemblages with equal or increased capability to retard radionuclide transport.			The halite and anhydrite of the host rock are stable in the expected repository environment. Alteration of carnallite and kieserite is not expected to contribute to increased radionuclide transport.	The evidence indicates that a favorable condition is present.

Table 6-10. Postclosure Technical Guidelines Requiring Site Characterization, Davis Canyon Site
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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(4) A combination of expected geochemical conditions and a volumetric flow rate of water in the host rock that would allow less than 0.001 percent per year of the total radionuclide inventory in the repository at 1,000 years to be dissolved.			Waste package failure under expected conditions is unlikely. Assuming waste package failure at 300 years, it is expected that less than 0.001 percent of the one-thousand-year waste inventory will be released.	The evidence indicates that a favorable condition is present.
(5) Any combination of geochemical and physical retardation processes that would decrease the predicted peak cumulative release of radionuclides to the accessible environment by a factor of 10 as compared to those predicted on the basis of ground-water travel time without such retardation.			Clay minerals will promote sorption along the expected flow path; anoxic deep basin brines will retard the migration of redox-sensitive radionuclides. Existing data are insufficient to quantify the decrease in peak cumulative release, which will be investigated further during detailed site characterization.	The evidence indicates that a favorable condition is not present.
(c) Potentially Adverse Conditions				
(1) Ground-water conditions in the host rock that could affect the solubility or the chemical reactivity of the engineered barrier system to the extent that expected repository performance could be compromised.			In the presence of unlimited volumes of low-magnesium brine, waste package lifetime is expected to exceed 10,000 years. Corrosion by limited volumes of either low- or high-magnesium brine yields a similar result.	The evidence indicates that a potentially adverse condition is not present.
(2) Geochemical processes or conditions that could reduce the sorption of radionuclides or degrade the rock strength.			Although small insignificant effects may occur, sorption and rock strength properties are expected to be largely unaltered.	The evidence indicates that a potentially adverse condition is not present.
(3) Prewaste-emplacement ground-water conditions in the host rock that are chemically oxidizing.			Geochemical evidence strongly suggests reducing conditions both in the host rock as well, in the Leadville Limestone Formation below the Salt Cycle 6 host horizon.	The evidence indicates that a potentially adverse condition is not present.
Rock Characteristics	960.4-2-3	6.3.1.3		
(a) Qualifying Condition				
The present and expected characteristics of the host rock and surrounding units shall be capable of accommodating the thermal, chemical, mechanical, and radiation stresses expected to be induced by repository construction, operation, and closure and by expected interaction among the waste, host rock, ground water, and engineered components. The characteristics of and the processes			The host rock and surrounding units are capable of withstanding the expected thermal, chemical, mechanical, and radiological stresses following closure.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

Table 6-10. Postclosure Technical Guidelines Requiring Site Characterization, Davis Canyon Site
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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
operating within the geologic setting shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements set forth in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.				
(b) Favorable Conditions				
(1) A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the underground facility to ensure isolation.			The proposed host rock, Paradox Formation Salt Cycle 6, is sufficiently thick and extensive to permit flexibility in locating the repository workings.	The evidence indicates that a favorable condition is present.
(2) A host rock with a high thermal conductivity, a low coefficient of thermal expansion, or sufficient ductility to seal fractures induced by repository construction, operation, or closure or by interactions among the waste, host rock, ground water, and engineered components.			Salt thermal conductivity is high. Salt fractures are expected to heal readily in and around the repository after closure.	The evidence indicates that a favorable condition is present.
(c) Potentially Adverse Conditions				
(1) Rock conditions that could require engineering measures beyond reasonable available technology for the construction, operation, and closure of the repository, if such measures are necessary to ensure waste containment or isolation.			Rock conditions are such that available technology is adequate to design, analyze, construct, and operate the repository.	The evidence indicates that a potentially adverse condition is not present.
(2) Potential for such phenomena as thermally induced fractures, the hydration or dehydration of mineral components, brine migration, or other physical, chemical, or radiation-related phenomena that could be expected to affect waste containment or isolation.			Expected repository temperatures will be lower than the temperature at which fractures could be thermally induced in salt. Under expected conditions, brine migration will not cause failure of the waste package. However, brine migration will result in corrosion of the waste package.	The evidence indicates that a potentially adverse condition is present.

Table 6-10. Postclosure Technical Guidelines Requiring Site Characterization, Davis Canyon Site
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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(3) A combination of geologic structure, geochemical and thermal properties, and hydrologic conditions in the host rock and surrounding units such that the heat generated by the waste could significantly decrease the isolation provided by the host rock as compared with pre-waste-emplacement conditions.			Thermomechanical modeling indicates that heat generated by the waste should not significantly decrease the host rock's isolation capabilities.	The evidence indicates that a potentially adverse condition is not present.
Climatic Changes				
(a) Qualifying Condition	960.4-2-4	6.3.1.4		
The site shall be located where future climatic conditions will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.			Climatic changes are expected to be the same as those experienced during the Quaternary. The effects on rates of erosion and salt dissolution are encompassed in estimated Quaternary rates; these have an insignificant impact.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
(b) Favorable Conditions				
(1) A surface-water system such that expected climatic cycles over the next 100,000 years would not adversely affect waste isolation.			The effects of expected increased precipitation, runoff, and infiltration would be negligible with respect to waste isolation.	The evidence indicates that a favorable condition is present.
(2) A geologic setting in which climatic changes have had little effect on the hydrologic system throughout the Quaternary.			Quaternary climatic changes are interpreted to have had an effect on the hydrologic system. Whether these constituted "little effect" is uncertain.	The evidence indicates that a favorable condition is not present.
(c) Potentially Adverse Conditions				
(1) Evidence that the water table could rise sufficiently over the next 10,000 years to saturate a previously unsaturated host rock.			The proposed host rock is within the saturated zone; therefore, the condition does not apply.	The evidence indicates that a potentially adverse condition is not applicable.
(2) Evidence that climatic changes over the next 10,000 years could cause perturbations in the hydraulic gradient, the hydraulic conductivity, the effective porosity, or the ground-water flux through the host rock and the surrounding geohydrologic units,	960.4-2-4	6.3.1.4	Porosity and conductivity along the expected flow path, from the proposed host rock to the accessible environment, would not be affected by climate. Increased precipitation and recharge would increase hydraulic gradients, but the effects of maximum rises in hydraulic	The evidence indicates that a potentially adverse condition is not present.

Table 6-10. Postclosure Technical Guidelines Requiring Site Characterization, Davis Canyon Site
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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
sufficient to significantly increase the transport of radionuclides to the accessible environment.			heads in recharge zones will have an insignificant effect on ground-water flow.	
Erosion	960.4-2-5	6.3.1.5		
(a) Qualifying Condition				
The site shall allow the underground facility to be placed at a depth such that erosional processes acting upon the surface will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.			Based on projections of Quaternary conditions, no radionuclide releases attributable to erosion are expected in less than a million years.	The evidence does not support a finding that the site is not likely to meet the qualifying conditions (Level 3).
In predicting the likelihood of potentially disruptive erosional processes, the DOE will consider the climatic, tectonic, and geomorphic evidence of rates and patterns of erosion in the geologic setting during the Quaternary period.				
(b) Favorable Conditions				
(1) Site conditions that permit the emplacement of waste at a depth of at least 300 meters below the directly overlying ground surface.			Depth of the proposed host rock at the site is approximately 885 meters (2,900 feet).	The evidence indicates that a favorable condition is present.
(2) A geologic setting where the nature and rates of the erosional processes that have been operating during the Quaternary Period are predicted to have less than one chance in 10,000 over the next 10,000 years of leading to releases of radionuclides to the accessible environment.			Incision in the next 10,000 years is projected to be approximately 4 meters (12 feet). Hence, there is no chance of radionuclide releases attributable to erosion.	The evidence indicates that a favorable condition is present.
(3) Site conditions such that waste exhumation would not be expected to occur during the first one million years after repository closure.			Projections of average Quaternary conditions indicate streams may erode 240 to 400 meters (800-1200 feet) in the next one million years. Hence, waste could not be exhumed during that time.	The evidence indicates that a favorable condition is present.

Table 6-10. Postclosure Technical Guidelines Requiring Site Characterization, Davis Canyon Site
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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(c) Potentially Adverse Conditions				
(1) A geologic setting that shows evidence of extreme erosion during the Quaternary Period.			The long-term stream incision rate in the site vicinity (0.24 to 0.40 meters ,0.8 to 1.2 foot. per 1,000 years) is not judged to be extreme.	The evidence indicates that a potentially adverse condition is not present.
(2) A geologic setting where the nature and rates of geomorphic processes that have been operating during Quaternary Period could, during the first 10,000 years after closure, adversely affect the ability of the geologic repository to isolate the waste.			Projections of Quaternary erosional rates indicate that the ability of the site to isolate the waste will not be adversely affected by erosion in the first 10,000 years after closure.	The evidence indicates that a potentially adverse condition is not present.
(d) Disqualifying Condition				
The site shall be disqualified if site conditions do not allow all portions of the underground facility to be situated at least 200 meters below the directly overlying ground surface.			The host rock is situated at a depth of approximately 885 meters (2,900 feet).	The evidence does not support a finding that the site is disqualified (Level 1).
Dissolution	960.4-2-6	6.3.1.6		
(a) Qualifying Condition				
The site shall be located such that any subsurface rock dissolution will be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.			Based on estimated rates of dissolution, it will not reach the repository within a period considerably longer than 10,000 years.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
In predicting the likelihood of dissolution within the geologic setting at a site, the DOE will consider the evidence of dissolution within that setting during the Quaternary Period, including the locations and characteristics of dissolution fronts or other dissolution features, if identified.				
(b) Favorable Condition				
No evidence that the host rock within the site was subject to significant dissolution during the Quaternary Period.			There is no evidence of Quaternary or earlier dissolution of the host rock in any core or geophysical logs from wells near the site.	The evidence indicates that a favorable condition is present.

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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(c) Potentially Adverse Conditions				
Evidence of significant dissolution within the geologic setting--such as breccia pipes, dissolution cavities, significant volumetric reduction of the host rock or surrounding strata, or any structural collapse--such that a hydraulic interconnection leading to a loss of waste isolation could occur.			There is evidence of significant dissolution within the geological setting.	The evidence indicates that a potentially adverse condition is present.
(d) Disqualifying Condition				
The site shall be disqualified if it is likely that, during the first 10,000 years after closure, active dissolution as predicted on the basis of the geologic record, would result in a loss of waste isolation.			Analyses indicate that the repository will remain isolated from dissolution for longer than 10,000 years.	The evidence does not support a finding that the site is disqualified (Level 1).
Tectonics	960.4-2-7	6.3.1.7		
(a) Qualifying Condition				
The site shall be located in a geologic setting where future tectonic processes or events will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.			The nature and rates of Quaternary tectonic processes and events show that there is very little likelihood of disruptive tectonic events during the next 10,000 years at the site.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
In predicting the likelihood of potentially disruptive tectonic processes or events, the DOE will consider the structural, geophysical, and seismic evidence for the nature and rates of tectonic processes and events in the geologic setting during the Quaternary Period.				
(b) Favorable Condition				
The nature and rates of igneous activity and tectonic processes (such as uplift, subsidence, faulting, or folding), if any, operating within the geologic setting during the Quaternary Period would, if continued into			No volcanism has occurred at the site during the Quaternary. The nearest Quaternary volcanism was more than 127 kilometers (79 miles) away. The geologic record indicates that tectonism in the geologic setting has been	The evidence indicates that a favorable condition is present.

Table 6-10. Postclosure Technical Guidelines Requiring Site Characterization, Davis Canyon Site
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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
the future, have less than one chance in 10,000 years after closure of leading to releases of radionuclides to the accessible environment.			dominated by regional uplift during the past 2 million to 3 million years.	
(c) Potentially Adverse Conditions				
(1) Evidence of active folding, faulting, diapirism, uplift, subsidence, or other tectonic processes or igneous activity within the geologic setting during the Quaternary Period.			The geologic record indicates Quaternary faulting in the geologic setting.	The evidence indicates that a potentially adverse condition is present.
(2) Historical earthquakes within the geologic setting of such magnitude and intensity that, if they recurred, could affect waste containment or isolation.			There is no historical record of earthquakes occurring in the geologic setting with magnitudes greater than M_L 4 to 5.	The evidence indicates that a potentially adverse condition is not present.
(3) Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or the magnitude of earthquakes within the geologic setting may increase.			A possibility exists that the Shay Graben fault could produce an earthquake larger than any historic seismicity.	The evidence indicates that a potentially adverse condition is present.
(4) More frequent occurrences of earthquakes or earthquakes of higher magnitude than are representative of the region in which the geologic setting is located.			The frequency and magnitude of seismic events within the Paradox Basin is less than or comparable to that of the central portion of the Colorado Plateau.	The evidence indicates that a potentially adverse condition is not present.
(5) Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such magnitudes that they could create large-scale surface-water impoundments that could change the regional ground-water flow system.			It is unlikely that a large impoundment should develop from natural phenomena near the site.	The evidence indicates that a potentially adverse condition is not present.
(6) Potential for tectonic deformations--such as uplift, subsidence, folding, or faulting--that could adversely affect the regional ground-water flow system.			The geologic record of the site show little evidence that tectonism has affected the regional groundwater flow system in the past.	The evidence indicates that a potentially adverse condition is not present.

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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(d) Disqualifying Condition				
A site shall be disqualified if, based on the geologic record during the Quaternary Period, the nature and rates of fault movement or other ground motion are expected to be such that a loss of waste isolation is likely to occur.			Known or suspected Quaternary faults are located a sufficient distance from the site that activity on these features is not expected to affect waste isolation.	The evidence does not support a finding that the site is disqualified (Level 1).
Human Interference/Natural Resources	960.4-2-8-1	6.3.1.8		
(a) Qualifying Condition				
The site shall be located such that--considering permanent markers and records and reasonable projections of value, scarcity, and technology--the natural resources, including ground water suitable for crop irrigation or human consumption without treatment, present at or near the site will not be likely to give rise to interference activities that would lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.			Little usable ground water is present at the site. The potential for undiscovered hydrocarbon resources is low, and the potential is also low for the occurrence and development, at the site, of other mineral resources identified in the Paradox Basin.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
(b) Favorable Conditions				
(1) No known natural resources that have or are projected to have in the foreseeable future a value great enough to be considered a commercially extractable resource.			Several natural resources that could be considered commercially extractable are present within the site.	The evidence indicates that a favorable condition is not present.
(2) Ground water with 10,000 parts per million or more of total dissolved solids along any path of likely radionuclide travel to the accessible environment.			TDS (total dissolved solids) concentrations along the flow path are approximately 100,000 parts per million.	The evidence indicates that a favorable condition is present.
(c) Potentially Adverse Conditions				
(1) Indications that the site contains naturally occurring materials, whether or not actually identified in such form that (i) economic extraction is potentially feasible during the foreseeable future or			Extraction of several naturally occurring materials has occurred at the site. However, uranium and potash resources are lower than elsewhere in southeastern Utah.	The evidence indicates that a potentially adverse condition is present.

Table 6-10. Postclosure Technical Guidelines Requiring Site Characterization, Davis Canyon Site
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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(ii) such materials have a greater gross value, net value, or commercial potential than the average for other areas of similar size that are representative of, and located in, the geologic setting.				
(2) Evidence of subsurface mining or extraction for resources within the site if it could affect waste containment or isolation.			There is subsurface mining near the site. However, it only extends to a maximum depth of 24 meters (80 feet).	The evidence indicates that a potentially adverse condition is not present.
(3) Evidence of drilling within the site for any purpose other than repository site evaluation to a depth sufficient to affect waste containment and isolation.			There are no known wells at the site that penetrate to the depth of the host rock.	The evidence indicates that a potentially adverse condition is not present.
(4) Evidence of a significant concentration of any naturally occurring material that is not widely available from other sources.			There are no concentrations of materials not widely available from other sources.	The evidence indicates that a potentially adverse condition is not present.
(5) Potential for foreseeable human activities--such as ground-water withdrawal, extensive irrigation, subsurface injection of fluids, underground pumped storage, military activities, or the construction of large-scale impoundments--that could adversely change portions of the ground-water flow system important to waste isolation.			Because of limited potable ground-water resources within and near the site, none of the human activities identified in the condition are expected to adversely change the ground-water system.	The evidence indicates that a potentially adverse condition is not present.
(d) Disqualifying Conditions				
A site shall be disqualified if				
(1) Previous exploration, mining, or extraction activities for resources of commercial importance at the site have created significant pathways between the projected underground facility and the accessible environment; or			There has been no deep mining or significant resource-related activity at the site, such as to create significant pathways.	The evidence does not support a finding that the site is disqualified (Level 1).
(2) Ongoing or likely future activities to recover presently valuable natural mineral resources outside the controlled area would be expected to lead to an inadvertent loss of waste isolation.			There are no presently valuable mineral resources in the site vicinity, the recovery of which would lead to an inadvertent loss of waste isolation.	The evidence does not support a finding that the site is disqualified (Level 1).

the WIPP Brine A, for which overpack corrosion rates have been measured. Furthermore, the performance assessment calculations in Section 6.4.2 use conservative assumptions that result in shorter calculated lifetimes of the waste package and greater calculated radionuclide releases than the expected values.

Analysis. The Cycle 6 host horizon contains small amounts of intergranular and fluid-inclusion brine as well as water that is present in hydrous mineralogical phases such as clays and carnallite. In general measured water contents of the salt are less than 0.530 weight percent; however, in zones containing hydrous evaporites the water content can be much higher (Hite, 1983; Conner, 1983). Based on conservative calculations of mean water contents of Cycle 6 halite, clay, and carnallite, the maximum amount of brine available for migration toward and corrosion of the waste package is estimated to be 4.7 volume percent and is expected to be significantly less under expected repository thermal conditions (Section 3.2.7.1). The 4.7 volume percent brine value is based on the following conservative estimates:

- 0.5 average weight percent water in Cycle 6 halite
- 1.0 average weight percent clay in Cycle 6 strata (Weaver et al., 1982; Hite, 1983; Padan et al., 1984) and 15.0 weight percent water in Cycle 6 clay (Weaver et al., 1983; Padan et al., 1984; Conner, 1983)
- 1.26 average weight percent water from carnallite (total theoretical yield at 200 C [363 F] Hite, 1983).

The performance assessment calculations conservatively assume 5.0 volume percent brine (Section 6.4.2.3.2). The brine is expected to be a high-magnesium (35,000 milligrams per liter) sodium chloride type if it originates from thermal dehydration of Cycle 6 bedrock (Table 6-11). An intrusive brine could be either a low-magnesium, sodium chloride type if it results from entry of ground water that flows through magnesium-poor strata or a higher-magnesium, sodium chloride type if it results from entry of ground water that flows through magnesium-rich (carnallite-, kieserite-rich) strata. An intrusive brine of low-magnesium content is expected to be the more probable scenario. Numerous processes are expected to restrict the magnesium content of an intrusion brine such as the precipitation of magnesium-bearing mineral phases and dilution by low-magnesium fluids (Section 6.3.1.2.3). The formation of intrusive brines of any type is considered to be highly unlikely.

The performance assessments presented in Section 6.4.2 suggest the following:

1. Waste package corrosion by unlimited quantities of low-magnesium intrusion brines under expected conditions would not lead to waste package failure within 10,000 years after burial. The unexpected condition of unlimited quantities of high-magnesium intrusion brine is predicted to lead to overpack failure at 336 and 220 years for commercial high-level waste (CHLW) and spent fuel from pressurized-water reactors (SFPWR), respectively. If a reason is found for expecting a large amount of high-magnesium brine at the repository horizon, the waste package will be designed to accommodate this.

2. Thermally induced brine migration will bring only a moderate volume of high-magnesium brine in contact with the waste package, and the high-magnesium brine that accumulates will not destroy the ability of the waste package to meet the requirements of 10 CFR 60.113.

3. A conservative case analysis of expected conditions shows that less than 0.001 percent of the 1,000-year radionuclide inventory would dissolve per year.

4. There are no driving forces that would cause release of dissolved radionuclides from the repository.

Table 6-11. Compositions of Simulated Salt Brines Used in Corrosion Tests (Ion Concentration, milligrams per liter)

Ion	Low Magnesium Content Brines		High Magnesium Content Brine
	Permian Basin No. 1[a]	Permian Basin No. 2[a]	Brine A
Na^+	123,000	123,000	42,000
Ca^{2+}	1,560	1,100	600
Mg^{2+}	134	122	35,000
K^+	39	39	30,000
Sr^{2+}	35	35	5
Zn^{2+}	7.8	7.9	(b)
Cl^-	191,000	191,000	190,000
SO_4^{2-}	3,200	1,910	3,500
HCO_3^-	30	23	700
Br^-	32	24	400
F^-	1.1	1.0	(b)
I^-	(b)	(b)	10
BO_3^{---}	(b)	(b)	1,200
pH	7.2	7.05	6.5

Note: The high magnesium content is considered representative of Paradox Basin thermally migrating brines. The low magnesium content brines are considered representative of Paradox Basin salt dissolution brines.

(a) Attempts to conduct corrosion experiments with Permian No. 1 brine led to the precipitation of protective anhydrite coatings on specimen surfaces, so the Permian Basin No. 1 brine was heated to operating temperatures (150 C [302 F]) to equilibrate and precipitate anhydrite and was renamed Permian Basin No. 2 before using it in corrosion tests.

(b) Not included in recipe.

The containment characteristics of the host salt could be compromised only by dissolution of the host rock. Section 6.3.1.6 indicates that dissolution is not an expected condition. Also, within the geologic setting, geochemical factors are expected to reduce the mobility of radionuclides within the ground-water system (Sections 6.3.1.2.2 and 6.3.1.2.3). Results of the evaluation are summarized in Table 6-9.

6.3.1.2.2 Analysis of Favorable Conditions.

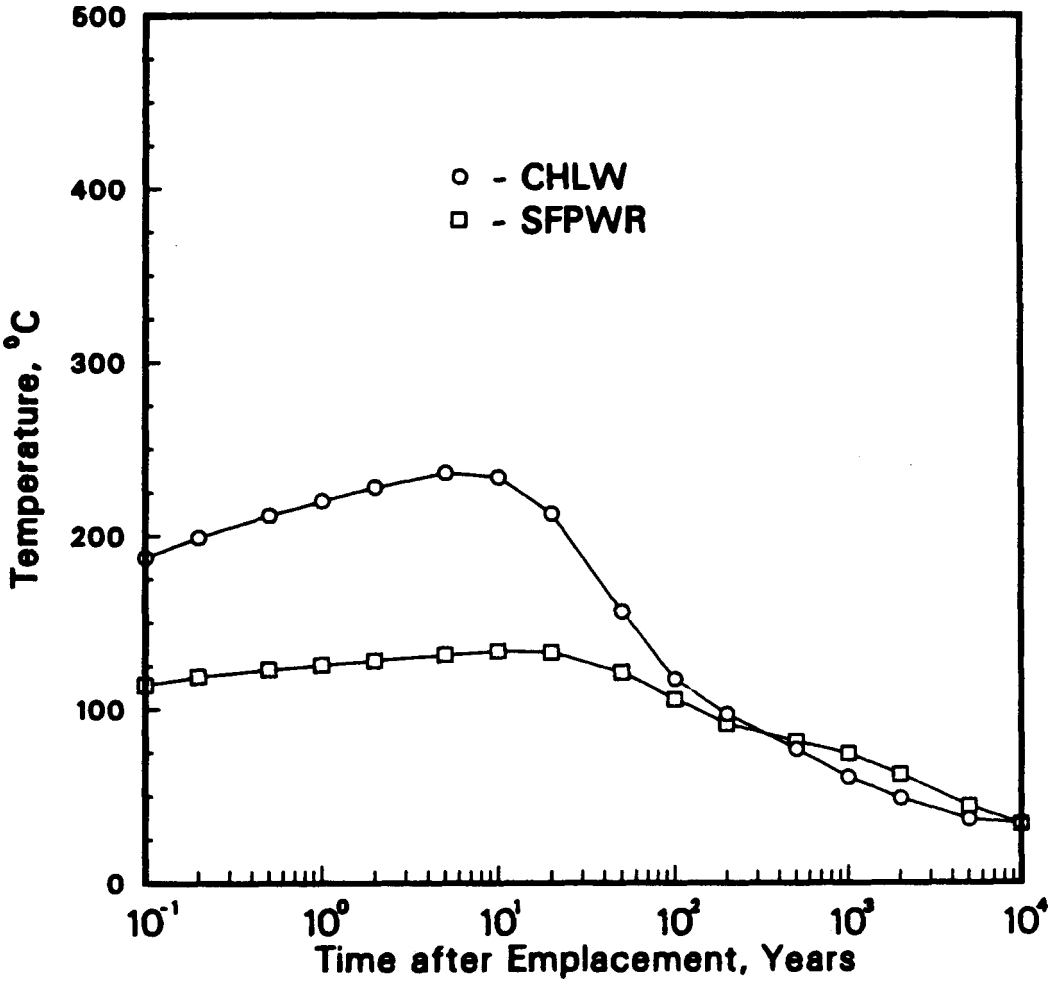
(1) The nature and rates of the geochemical processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years.

Evaluation. Geochemical processes that, if operative, could adversely affect the ability of the geologic repository to isolate the waste could include, but not be limited to, the following: (1) host rock alteration by migrating hydrothermal brines, such as sulfatization, secondary dolomitization, hydration and dehydration; (2) large-scale salt dissolution; and (3) dissolution or hydrometamorphic alteration of the late-forming, soluble minerals (e.g., carnallite and kieserite). There is no evidence of alteration by migrating hydrothermal brines; however, carnallite and kieserite have been identified in the upper section of the Cycle 6 interval. Therefore large-scale salt dissolution and the hydrometamorphic alteration of carnallite and kieserite are the principal processes that could potentially affect the ability of the repository to isolate waste. The evaluation of dissolution in the site geologic setting during the Quaternary period is addressed in Section 6.3.1.6; it is concluded that there are no indications of Quaternary-age dissolution at the site. The locations of known and suspected dissolution features are provided in Sections 6.3.1.6.1 and 3.2.5.6. None of these features are believed to be indicative of processes that could affect the isolation capabilities of the site during the next 10,000 years.

Under the expected repository thermal conditions of less than 250 C (482 F) in the near-field (Figure 6-1) and less than 120 C (248 F) at a distance of 5 meters (16 feet) or more from the waste package (Figures 6-2 and 6-3), hydrometamorphic mineralogical reactions such as hydration, dehydration, and recrystallization may be of concern, but melting is considered unlikely. The carnallite marker bed in Salt Cycle 6 consists primarily of a mixture of halite (91.4 to 96.4 weight percent), carnallite (0.53 to 4.62 weight percent), kieserite (0.01 to 2.04 weight percent), anhydrite (1.54 to 2.9 weight percent) and sylvite (Hite, 1982; Hite, 1983; Fukui and Hopping, 1984). The melting points of these minerals are as follows: halite, 800 C (1472 F); carnallite, 265 C (509 F); kieserite, 365 C (689 F); anhydrite, 1450 C (2642 F); and sylvite, 770 C (1418 F) (Weast, 1984). Certain evaporite minerals undergo phase transformations at temperatures well below their melting points, and the chemical composition of the transformation products depends on the chemical compositions of the fluids in equilibrium with them. For example, at 83 C (181 F) and in NaCl-KCl saturated solutions, carnallite incongruently alters to halite and sylvite (Braitsch, 1971). In $MgSO_4$-bearing systems and at temperatures exceeding 72 C (162 F), kieserite and sylvite form at the expense of carnallite, kieserite, and halite (Braitsch, 1971). Thus, the lower melting hydrous phases tend to convert to higher melting anhydrous phases when exposed to elevated temperatures.

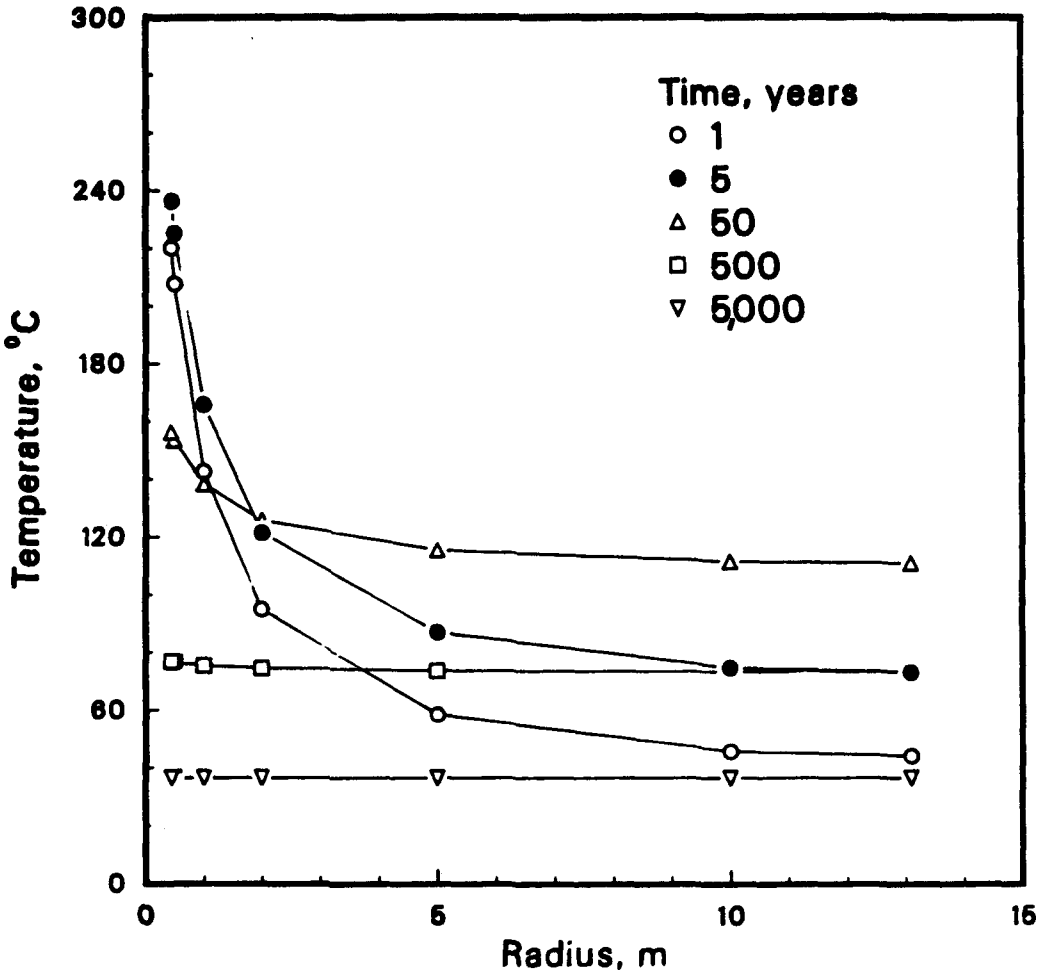
The mineral transformation reactions are accompanied by a volume change, the direction of which depends on whether the brine is retained in the near-field or migrates away. For example, the transformation of carnallite to sylvite plus brine results in a 13 percent increase in volume when the brine is retained in the near-field and a 78 percent decrease in volume when the brine migrates away (Holser, 1979). Assuming an average carnallite content of 2.39 weight percent in upper Cycle 6 salt (Hite, 1982) and that all of the carnallite is converted to sylvite and brine, which remains in place, the expected increase in volume in Cycle 6 strata is only 0.32 percent. If brine is release from the carnallite-rich zones, the maximum expected reduction in Cycle 6 volume is 1.86 percent.

Consequently, the major evaporite phases present in the carnallite marker bed in Salt Cycle 6 are not expected to melt at the maximum near-field repository temperature, and they tend to combine with other minerals to form more stable phases. The mineral transformation



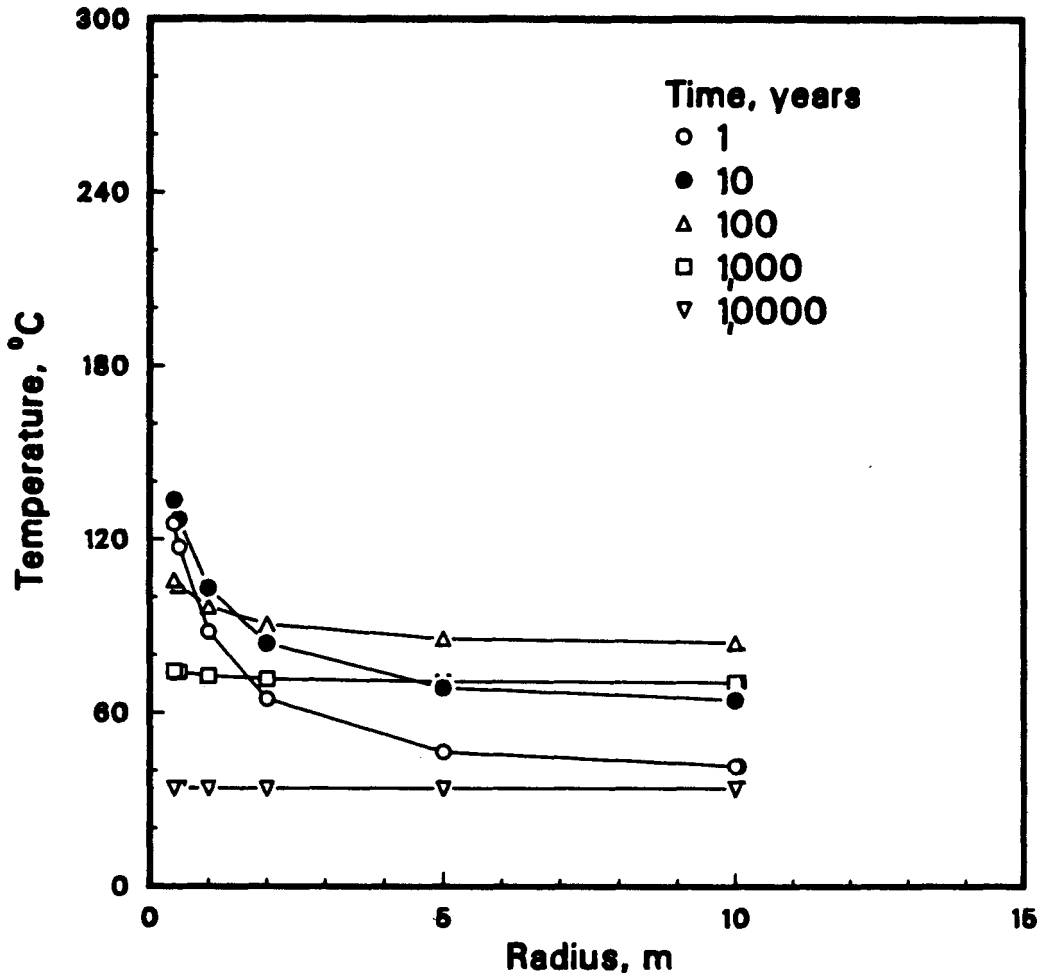
TEMPV5 Temperatures Versus Time at Salt-Overpack Interface for Davis Canyon

Figure 6-1



Temperatures Around CHLW
Waste Package at
Davis Canyon

Figure 6-2



Temperatures Around SFPWR
Waste Package at
Davis Canyon

Figure 6-3

reactions are accompanied by small changes in volume. Even if melting did occur, the permeability of halite is such that the fluids would probably remain in place and not migrate. Finally, if in the future a reasonable scenario for melting is identified, then repository and waste package designs can be modified appropriately (e.g., by lowering the thermal loading).

The evidence indicates that the favorable condition is present.

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

Evaluation. This guideline is applied to conditions both within the host rock as well as to deep-basin aquifers above and below the Cycle 6 salt host horizon.

Precipitation of Radionuclides in the Host Salt. Although quantitative mineralogical and geochemical details on the host rock are not available at present, the preliminary analyses by McCulley et al. (1984) and Hite (1983) suggest the presence of reduced forms of carbon, iron, and sulfur in both Salt Cycle 6 and the clastic interbeds. Methane contents are as high as 1 cubic centimeter (0.06 cubic inch) gas per kilogram of salt (Hite, 1983, Table 5). Insoluble organic carbon contents of Salt Cycle 6 are as high as 0.5 weight percent (Hite, 1983, Table 2; Padan et al., 1984). The Salt Cycle 6 host horizon is bounded above and below by carbonate and clastic beds for which there is strong evidence of chemically reducing conditions (Section 3.2.7), which will promote the precipitation of many redox-sensitive radionuclides such as technetium, neptunium, uranium, and plutonium. In addition certain radionuclides (strontium and radium) form relatively insoluble sulfate and carbonates (Langmuir and Riese, 1985; Stumm and Morgan, 1970).

Gamma radiolysis may alter ground-water redox states through the production of species such as hydrogen peroxide, oxygen, hydrogen, chlorine, and possibly perchlorate (Panno and Czyscinski, 1984). Similar effects are predicted from alpha radiolysis of brines (Pederson et al., 1984), which will not occur until waste package failure. Brine radiolysis reactions have been experimentally documented at dose rates many orders of magnitude greater than that expected at the waste package surface, and will be localized to the near-field repository environment, should they occur (Levy and Kierstead, 1982; Panno and Soo, 1983). If future research demonstrates significant brine radiolysis at expected repository dose rates, then engineering measures can be implemented to reduce radiation dose rates and to minimize any associated adverse effects.

Precipitation of Radionuclides Outside the Host Salt. Ground water in the lower hydrostratigraphic unit below the host salt consists of brines containing methane (1.14 to 5.43 volume percent), ethane (0.3 to 0.6 volume percent), and sulfide (30 to 80 milligrams per liter) and is therefore considered (Section 3.2.7.2) to be chemically reducing (McCulley et al., 1984; WCC, 1982, ONWI-290, Vol. II, pp. 9-25). Platinum electrode Eh measurements range from -80 to -240 mV for lower hydrostratigraphic unit formation fluids (McCulley et al., 1984). Sulfate/sulfide redox couple calculations yield Eh values of -113 to -143 mV, which are in good agreement with measured Eh (McCulley et al., 1984). Measured and calculated Eh values are within the stability field of pyrite, which is present in both the Paradox Formation and Leadville Limestone in limited concentrations. Microbially mediated reduction of sulfate to sulfide actively occurs in the Leadville Limestone (McCulley et al., 1984). Measured Eh and calculated values from the sulfur redox couple are not in agreement with calculated values from the iron and arsenic redox couples; however, iron and arsenic speciation in the lower hydrostratigraphic samples analyzed was believed to have been altered because of sample contamination (McCulley et al., 1984). Lindberg and Runnells (1984) point out that obtaining reliable Eh measurements in ground water is problematic; however, the presence of redox-sensitive species such as sulfide and methane can provide at least a qualitative guide to the redox status of water.

At these lower redox potentionals expected in the lower hydrostratigraphic unit, redox-sensitive radionuclides are expected to be stable in their lower oxidation states. The retention of radionuclides such as uranium, neptunium, plutonium, and technetium is greatly increased under reducing conditions because these elements form compounds having much lower solubilities than those formed under oxidizing conditions (Cleveland et al., 1983; Cleveland, 1979a, b; Bondietti and Francis, 1979; Langmuir, 1978).

Sorption. The primary mineral constituents of Salt Cycle 6 are halite, anhydrite, carnallite, and kieserite, with trace amounts of sylvite, magnesium-borates, magnesite, quartz, dolomite, calcite, talc, and clays (Section 3.2.7.1). Thin wave-like anhydrite bands in Salt Cycle 6 occur as interbeds and contain small quantities of clays. The clays present in the salt unit and the interbeds are composed of illite, chlorite, smectite, vermiculite, talc, corrensite, randomly interstratified chlorite/smectite, chlorite/vermiculite, and talc/chlorite (Bodine and Rueger, 1984; Padan et al., 1984). Above and below salt Cycle 6 is flanked on the clastic interbeds are present which consist of calcareous shales, silty-limestone/dolomite, and anhydrite. While some radionuclide adsorption can be expected from clays dispersed in the salt and localized in the clastic interbeds, the conservative performance assessments in Section 6.4.2 do not take credit for retardation by sorption process.

Colloid Formation. Brines promote the conversion of stable hydrophilic colloidal suspensions to unstable hydrophobic colloids (Stumm and Morgan, 1970, pp. 500-507). The conversion process is accompanied by colloid growth and charge reversal, resulting in large relatively immobile particles that can be more effectively filtered by geological substrates. Evidence on the deposition of plutonium-bearing particles and flocculation of organo-metallic colloids suggests that this phenomenon is operative in estuarine water and sea water (Hamilton, 1985; Coonley et al., 1971). However, the applicability of this phenomenon to site-specific Paradox Basin brine environments needs to be established further as: (1) there is no general quantitative theory to predict the size to which hydrophobic colloids will grow, and (2) the ultimate transportability of such colloids in ground water will depend both upon their size and charge characteristics as well as the hydrogeochemical characteristics of the repository environment.

Inorganic Complexs. The uranium-bearing specie, $(UO_2[CO_3]_3^{-4})$ which contains hexavalent uranium, can be thermodynamically stable under reducing conditions (Garrels and Christ, 1965, Figure 7.32b). Reduced plutonium may also complex significantly with certain inorganic ions (Cleveland, 1979b). The thermodynamic data base used for calculating radionuclide solubility and speciation in water is probably not adequate for definitive calculations. The effects of high ionic strength media, temperature, and pressure constitute additional sources of uncertainty.

Organic Complexes. Of the drill-stem test (DST) fluids collected from the Leadville Limestone at GD-1, only one sample contained no detectable drilling fluid contamination. The total organic carbon concentration of this sample as measured in two different laboratories was 15 (McCulley et al., 1984) and 12.8 milligrams per liter (Means et al., 1983, ONWI-448). Sample volumes available were insufficient for detailed organic geochemical analysis; however, McCulley et al. (1984) report the presence of short-chain aliphatic acids in this and DST fluids containing low but detectable drilling fluid contamination. While available organic geochemical data (Section 3.2.7.2) on deep Paradox Basin brines are insufficient to reach definitive conclusions, if short-chain aliphatic acid anions are the principal organic species present, then significant radionuclide complexation would not be expected (Means and Hubbard, 1985, BMI/ONWI-578).

Methane and ethane are the principal organic gases present in Paradox Basin brines (McCulley et al., 1984). The radiolysis of these organic gases will probably form polyethylene or low molecular weight organic species, such as formic acid in addition to carbon dioxide and water (Lind, 1961; Gray, 1984). None of the expected radiolytic by-products possess significant radionuclide complexation characteristics. The speciation and amount of organic matter contained in Salt Cycle 6 halite and possible effects on radionuclide complexation have not yet been evaluated.

In conclusion, the Cycle 6 interval and stratigraphic units surrounding Cycle 6 are expected to be chemically reducing, which will promote the precipitation of certain redox-sensitive radionuclides, should waste package failure occur. Others may form insoluble sulfates or carbonates, or be adsorbed by clay minerals present in either Cycle 6 or adjacent clastic strata. The formation of certain types of colloids is expected to be inhibited by the destablizing effects of brines, and preliminary organic geochemical data on deep basin brines suggest only low concentrations of weak organic complexing agents. Therefore, geochemical conditions at the Davis Canyon site are expected to be conducive to waste isolation.

The evidence indicates that the favorable condition is present.

> (3) Mineral assemblages that, when subjected to expected repository conditions, would remain unaltered or would alter to mineral assemblages with equal or increased capability to retard radionuclide transport.

Evaluation. The host salt can undergo changes resulting from radiation and heat. Adverse effects from radiation are expected to be mitigated by the fact that the expected dose rate on the exterior of the overpack surface is only approximately 20 Rads per hour (Jansen, 1985). Gamma irradiation of halite can produce sodium metal and free chlorine; however, the effect is very localized and experimentally documented only for total doses exceeding 10^7 Rads (Levy and Kierstead, 1982; Panno and Soo, 1983). Also, if free chlorine does not evolve from the salt, the decomposition products may react back to form sodium chloride (Pederson et al., 1984). The radiolytic decomposition of halite has not been documented at expected dose rates of approximately 20 rads per hour at the waste package surface. If future research shows that such dose rates initiate processes that adversely affect rock strength, then engineering variables such as canister thickness can be adjusted to minimize such effects.

Clay minerals will undergo thermal dehydration resulting in changes in the physical properties of the affected clay layers. Any associated volume reduction is expected to be offset by salt creep and expansion around the waste package.

The Salt Cycle 6 carnallite marker bed above the repository host horizon contains about 0.53 to 4.62 weight percent carnallite (with 0.01 to 2.04 weight percent kieserite) at the GD-1 borehole located 5 kilometers (3 miles) northeast of the site (Hite, 1982; 1983; Bodine and Rueger, 1984). Examination of available geophysical logs (Hite, 1982) suggests that the carnallite layer may decrease in thickness toward the site. Carnallite and kieserite melt at 265 C (509 F) and 365 C (689 F) (Weast, 1984) respectively, although some evidence suggests that they may begin to melt incongruently at somewhat lower temperatures. Under expected repository conditions, the maximum temperatures to which these evaporite minerals will be exposed are 90 to 120 C (194 to 248 F) (Figures 6-2 and 6-3). In this temperature range carnallite and kieserite may undergo phase transformations (Braitsch, 1971), and the expected transformation products are largely phases such as halite and sylvite, which melt at 800 C (1472 F) and 770 C (1418 F), respectively (Weast, 1984). The transformation of carnallite to sylvite plus brine results in a 13 percent increase in volume when the brine is retained in the near-field and a 78 percent decrease in volume if the brine migrates away (Holser, 1979). If all of the carnallite (2.39 weight percent [Hite, 1982]) in upper Cycle 6 salt were to convert to sylvite and brine, and remain in place, the resulting increase in volume would be only 0.31 percent. If brine is released from the carnallite-rich zone, the maximum expected reduction in Cycle 6 volume is 1.86 percent.

The evidence indicates that the favorable condition is present.

> (4) A combination of expected geochemical conditions and a volumetric flow rate of water in the host rock that would allow less than 0.001 percent per year of the total radionuclide inventory in the repository at 1,000 years to be dissolved.

Evaluation. Under expected conditions, water contacting the waste will be restricted to brine inclusions and intergranular water in halite, which will migrate up the thermal gradient, and dehydration water from clays and carnallite. The amount of brine contacting the

waste package has been conservatively calculated not to exceed 4.68 volume percent at the Davis Canyon site (Section 3.2.7.1). Realistic estimates are more on the order of 1.3 to 3.5 volume percent brine (Section 3.2.7.1). Assuming that 5.0 volume percent brine is available for waste package corrosion, the assessments of waste package performance show that package failure is unlikely (Section 6.4.2). The expected release (none) demonstrates this favorable condition.

One set of conservative (i.e., deliberately overestimated) calculations has been made to investigate radionuclide release from hypothetically breached waste packages (Jansen, 1985). The critical assumptions are that (1) the waste package fails (NRC requires the waste package to last for at least 300 years); (2) as the brine reaches the waste package, it becomes saturated instantly with each radionuclide; (3) conservatively high saturation values for each radionuclide are used; and (4) no brine is consumed by reaction with the waste package. Jansen's calculations are summarized in Tables 6-12 and 6-13. These tables show that this favorable condition is met for the sum of all radionuclides prior to 1,000 years. (Note that the alternate condition of these tables is based on the 10 CFR Part 60 regulation which requires a fractional release of 10^{-8}per year, while the favorable condition for this guideline is 10^{-5}per year summed over all radionuclides, i.e., sum the alternate condition columns and divide by 1,000 for comparison with the guideline.) Therefore, the criterion is expected to be met.

Another set of conservative calculations made by Jansen (1985) assumes (1) ground water flows through the salt, and (2) radionuclides are released as the waste matrix is dissolved. These assumptions are conservative in that impermeable zones surrounding the repository horizon should minimize or preclude flow. The CHLW and SFPWR releases estimated by these calculations are still below the guideline rate of 10^{-5} per year needed for long half-life radionuclides.

The thermodynamic data base on radionuclide solubilty contains uncertainties and assumptions. The solubility calculations will be updated as further information becomes available. The effect of radiolysis on geochemical conditions around the waste package is also not completely understood. Certain adverse effects have been noted at high dose rates such as 10^5 rads per hour (Kreiter, 1984). Expected dose rates at the overpack surface are on the order to 20 rads per hour, where little or no adverse radiation effects have been documented. The introduction of atmospheric oxygen may create oxidizing conditions that are expected to be short-lived because of oxygen consumption by the metallic iron overpack (Jantzen, 1982).

The evidence indicates that the favorable condition is present.

> (5) Any combination of geochemical and physical retardation processes that would decrease the predicted peak cumulative releases of radionuclides to the accessible environment by a factor of 10 as compared to those predicted on the basis of ground-water travel time without such retardation.

Evaluation. The presence of clays (Section 3.2.7.1) is expected to promote sorption along the expected flow path, and anoxic deep basin brines (Section 3.2.7.2) are expected to retard redox-sensitive radionuclides. However, insufficient evidence is currently available to quantify the decrease in the peak cumulative release.

The evidence indicates that the favorable condition is not present.

6.3.1.2.3 Analysis of Potentially Adverse Conditions.

> (1) Ground-water conditions in the host rock that could affect the solubility or the chemical reactivity of the engineered-barrier system to the extent that the expected repository performance could be compromised.

Table 6-12. Davis Canyon CHLW Package. Comparison of Package Release Rates to Saturate Incoming Brine at the Waste Package Boundary with NRC Engineered System Release Rate Limits in 10 CFR Part 60

Element	Solubility[a], grams/m^3	300 yr Package Inventory,[b] grams	Quantity Required to Saturate Incoming Brines, grams/yr	Nuclide	Activity From Package to Brine, Curies/yr	Ratio to 1,000-yr Nuclide Activity/ (1E-5 per yr)	Ratio to 1,000-yr Total Activity/ (1E-8 per yr)
Carbon	0.06	1,608[c]	1.2E-5	C-14	1.1E-7	8.3E-4	(d)
Selenium	0.001	539	2.0E-7	Se-79	1.5E-9	3.8E-5	(d)
Strontium	0.8	3,375	1.6E-4	Sr-90	2.1E-5	83,000.	0.55
Technetium	0.001	7,368	2.0E-7	Tc-99	3.5E-9	2.8E-6	(d)
Tin	0.0001	915	2.0E-8	Sn-126	1.7E-10	2.2E-6	(d)
Iodine	600,000.	2,238[c]	120.	I-129	0.017	5500.	430
Cesium	600,000.	13,664	120.	Cs-135	0.029	900.	760
				Cs-137	6.9	9.5E+9	180,000
Thorium	0.001	0.090	2.0E-7	Th-232	3.6E-15	0.18	(d)
Uranium	0.001	46,153	2.0E-7	U-233	1.9E-14	9.5E-8	(d)
				U-235	3.8E-15	4.4E-7	(d)
				U-236	5.7E-14	4.1E-7	(d)
				U-238	6.8E-14	4.4E-7	(d)
Neptunium	0.001	5,940	2.0E-7	Np-237	1.4E-10	2.6E-6	(d)
Plutonium	0.001	540	2.0E-7	Pu-238	1.2E-8	8.7E-4	(d)
				Pu-239	6.2E-9	3.3E-5	(d)
				Pu-240	2.2E-8	4.1E-5	(d)
				Pu-241	5.6E-10	4.5E-5	(d)
				Pu-242	3.2E-11	3.7E-5	(d)
Americium	0.0001	3,730	2.0E-8	Am-241	5.5E-8	1.7E-6	(d)
				Am-243	8.5E-10	5.9E-7	(d)
Curium	0.001	8.6	2.0E-7	Cm-244	3.0E-9	1.0E+9	7.8E-5

Table 6-12. Davis Canyon CHLW Package. Comparison of Package Release Rates to Saturate Incoming Brine at the Waste Package Boundary with NRC Engineered System Release Rate Limits in 10 CFR Part 60
(Page 2 of 2)

Element	1,000 year Package Inventory, grams	Nuclide	Ratio of Radioactivity in Brine to NRC Limit Using 1,000 yr Inventory, Fraction of E-5 per year per Nuclide Inv. 200 yr	300 yr	500 yr	1,000 yr	of 1E-8 per year per Total Activity 200 yr	300 yr	500 yr	1,000 yr
Carbon	1,608	C-14	1.3E-3	8.3E-4	3.4E-4	5.2E-5	4.4E-3	2.8E-3	1.2E-3	1.8E-4
Selenium	538	Se-79	5.9E-5	3.8E-5	1.6E-5	2.6E-6	5.9E-5	3.8E-5	1.6E-5	2.6E-6
Strontium	3,351	Sr-90	1.4E-6	8.3E+4	300	3.3E-4	9.0	0.55	2.0E-3	2.2E-9
Technetium	7,351	Tc-99	4.3E-6	2.8E-6	1.2E-6	1.9E-7	1.4E-4	9.0E-5	3.8E-5	6.1E-6
Tin	913	Sn-126	3.4E-6	2.2E-6	9.5E-7	1.5E-7	6.6E-6	4.3E-6	1.8E-6	2.9E-7
Iodine	2,238	I-129	8,400	5,500	2,300	370	6.6E+2	4.3E+2	1.8E+2	2.9E+1
Cesium	13,607	Cs-135	1,400	900	380	61	1.2E+3	7.6E+2	3.2E+2	5.2E+1
		Cs-137	1.5E+11	9.5E+9	4.0E+7	61	2.8E+6	1.8E+5	7.5E+2	1.2E-3
Thorium	0.136	Th-232	0.28	0.18	0.071	0.010	1.5E-10	9.5E-11	3.8E-11	5.5E-12
Uranium	46,175	U-233	1.0E-7	9.5	8.1E-8	3.0E-8	5.4E-10	5.0E-10	4.3E-10	1.6E-10
		U-235	6.7E-7	4.4E-7	1.9E-7	3.0E-8	1.5E-10	9.8E-11	4.2E-11	6.7E-12
		U-236	6.2E-7	4.1E-7	1.8E-7	3.0E-8	2.2E-9	1.5E-0	6.4E-10	1.1E-10
		U-238	6.8E-7	4.4E-7	1.9E-7	3.0E-8	2.7E-9	1.8E-9	7.5E-10	1.2E-10
Neptunium	7,987	Np-237	3.9E-6	2.6E-6	1.1E-6	1.7E-7	5.8E-6	3.7E-6	1.6E-6	2.5E-7
Plutonium	564	Pu-238	2.1E-3	8.7E-4	1.5E-4	2.5E-6	7.2E-4	3.0E-4	5.2E-5	8.4E-7
		Pu-239	4.9E-5	3.3E-5	1.4E-5	2.5E-6	2.4E-4	1.6E-4	7.1E-5	1.2E-5
		Pu-240	6.4E-5	4.1E-5	1.7E-5	2.5E-6	8.8E-4	5.6E-4	2.3E-4	3.4E-5
		Pu-241	7.4E-5	4.5E-5	1.7E-5	2.5E-6	2.4E-5	1.4E-5	5.3E-6	7.9E-7
		Pu-242	5.7E-5	3.7E-5	1.6E-5	2.5E-6	1.3E-6	8.3E-7	3.5E-7	5.5E-8
Americium	1,683	Am-241	2.7E-6	1.7E-6	6.7E-7	8.2E-8	2.3E-3	1.4E-3	5.7E-4	7.0E-5
		Am-243	8.0E-7	5.8E-7	3.1E-7	8.2E-8	3.0E-5	2.2E-5	1.2E-5	3.1E-6
Curium	8.0	Cm-244	7.2E+10	1.0E+9	2.1E+5	1.7E-4	5.4E-3	7.8E-5	1.6E-8	1.3E-17
Brine Rate with zero threshold thermal gradient, (m^3/yr)			3.1E-4	2.0E-4	8.7E-5	1.4E-5	3.1E-4	2.0E-4	8.7E-5	1.4E-4

Note: The gross brine inflow rate is 2.0E-4 m^3 per year at 300 years after burial.

(a) Various other solubility data exist, some with higher and some with lower values for various nuclides. These other data may be no more or no less applicable for this preliminary analysis. More specifically, carbon solubility data could be controlled by kinetics and not by equilibrium conditions.
(b) The thorium, neptunium, and plutonium grow larger with time, so that at 10,000 years, these inventories are 1.1, 8,905, and 703 grams per package, respectively.
(c) This element is not in the CHLW package, it would be separated in the fuel reprocessing plant and stored separately.
(d) This value is not shown unless the primary (10^{-5}) standard is not met, indicated by a value greater than one in the preceding column.

Table 6-13. Davis Canyon SFPWR Package. Comparison of Package Release Rates to Saturate Incoming Brine at the Waste Package Boundary with NRC Engineered System Release Rate Limits in 10 CFR Part 60

Element	Solubility[a], grams/m^3	300-yr Package Inventory[b], grams	Quantity Required to Saturate Incoming Brines, grams/yr	Nuclide	Activity From Package to Brine, Curies/yr	Ratio to 1,000 yr Nuclide Activity/ (1E-5 per yr)	Ratio to 1,000 yr Total Activity/ (1E-8 per yr)
Carbon	.06	833	2.6E-5	C-14	2.3E-7	3.4E-3	(c)
Selenium	0.001	279	4.3E-7	Se-79	3.1E-9	1.6E-4	(c)
Strontium	0.8	1,747	3.4E-4	Sr-90	4.4E-5	340,000.	0.53
Technetium	0.001	3,812	4.3E-7	Tc-99	7.3E-9	1.1E-5	(c)
Tin	0.0001	19,216	4.3E-8	Sn-126	8.6E-12	2.3E-7	(c)
Iodine	600,000.	1,157	260.	I-129	0.035	22,000.	410.
Cesium	600,000.	7,069	260.	Cs-135	0.061	3,700.	720.
				Cs-137	15.	3.9E+10	170,000.
Thorium	0.001	1.19	4.3E-7	Th-232	6.4E-15	9.8E-3	(b)
Uranium	0.001	4,774,600	4.3E-7	U-233	2.6E-16	1.6E-9	(b)
				U-235	7.9E-15	8.9E-9	(b)
				U-236	1.2E-13	8.7E-9	(b)
				U-238	1.4E-13	9.0E-9	(b)
Neptunium	0.001	4,276	4.3E-7	Np-237	3.0E-10	6.1E-6	(c)
Plutonium	0.001	38,380	4.3E-7	Pu-238	1.2E-8	2.5E-4	(c)
				Pu-239	1.7E-8	1.1E-6	(c)
				Pu-240	2.9E-8	1.2E-6	(c)
				Pu-241	8.6E-11	1.3E-5	(c)
				Pu-242	9.5E-11	1.1E-6	(c)
Americium	0.0001	4,301	4.3E-8	Am-241	1.3E-7	3.1E-6	(c)
				Am-243	8.0E-10	1.1E-6	(c)
Curium	0.001	4.5	4.3E-07	Cm-244	6.3E-9	4.2E+9	7.4E-5

Table 6-13. Davis Canyon SFPWR Package. Comparison of Package Release Rates to Saturate Incoming Brine at the Waste Package Boundary with NRC Engineered System Release Rate Limits in 10 CFR Part 60

Element	1,000 year Inventory, grams	Nuclide	Ratio of Radioactivity in Brine to NRC Limit Using 1,000 yr Inventory, Fraction of 1E-5 per Year per Nuclide Inv. 200 yr	300 yr	500 yr	1,000 yr	of 1E-80 per Year per Total Activity 200 yr	300 yr	500 yr	1,000 yr
Carbon	833	C-14	4.3E-3	3.4E-3	2.0E-3	1.0E-3	3.4E-3	2.7E-3	1.6E-3	7.9E-4
Selenium	278	Se-79	2.0E-4	1.6E-4	9.6E-5	5.0E-5	4.6E-5	3.6E-5	2.3E-5	1.2E-5
Strontium	1,736	Sr-90	4.6E+5	3.4E+5	1.8E+3	6.4E-3	7.1	0.53	2.8E-3	9.8E-9
Technetium	3,804	Tc-99	1.4E-5	1.1E-5	7.0E-5	3.7E-6	1.1E-4	8.5E-5	5.3E-5	2.8E-5
Tin	19,217	Sn-126	2.9E-7	2.3E-7	1.4E-7	7.2E-8	1.3E-7	1.0E-7	6.2E-8	3.2E-8
Iodine	1,157	I-129	2.8E+4	2.2E+4	1.4E+4	7.2E+3	5.2E+2	4.1E+2	2.5E+2	1.3E+2
Cesium	7,036	Cs-135	4.6E+3	3.7E+3	2.3E+3	1.2E+3	9.1E+2	7.2E+2	4.5E+2	2.3E+2
		Cs-137	4.9E+11	3.9E+10	2.4E+8	1.2E+3	2.2E+6	1.7E+5	1.0E+3	5.2E-3
Thorium	4.9	Th-232	1.3E-2	9.8E-3	5.7E-3	2.9E-3	9.9E-11	7.5E-11	4.4E-11	2.2E-11
Uranium	4,775,930	U-233	1.4E-9	1.6E-9	2.2E-9	2.9E-9	2.6E-12	3.1E-12	4.1E-12	5.5E-12
		U-235	1.1E-8	8.9E-9	5.5E-9	2.9E-9	1.2E-10	9.2E-11	5.7E-11	3.0E-11
		U-236	1.1E-8	8.7E-9	5.4E-9	2.9E-9	1.7E-9	1.4E-9	8.6E-10	4.6E-10
		U-238	1.1E-8	9.0E-9	5.6E-9	2.9E-9	2.1E-9	1.7E-9	1.0E-9	5.4E-10
Neptunium	7,021	Np-237	7.8E-6	6.1E-6	3.8E-6	2.0E-6	4.5E-6	3.5E-6	2.2E-6	1.1E-6
Plutonium	37,011	Pu-238	6.8E-4	2.5E-4	3.2E-5	3.8E-7	3.9E-4	1.4E-4	1.8E-5	2.1E-7
		Pu-239	1.5E-6	1.1E-6	7.1E-7	3.8E-7	2.6E-4	2.0E-4	1.3E-4	6.7E-5
		Pu-240	1.5E-6	1.2E-6	7.4E-7	3.8E-7	4.3E-4	3.3E-4	2.0E-4	1.0E-4
		Pu-241	5.8E-5	1.3E-5	7.3E-7	3.8E-7	4.3E-6	1.0E-6	5.5E-8	2.8E-8
		Pu-242	1.4E-6	1.1E-6	7.0E-7	3.8E-7	1.4E-6	1.1E-6	6.9E-7	3.7E-7
Americium	1,642	Am-241	4.0E-6	3.1E-6	1.8E-6	8.5E-7	2.0E-3	1.6E-3	9.4E-4	4.3E-4
		Am-243	1.2E-6	1.1E-6	8.7E-7	8.5E-7	1.0E-5	9.4E-6	7.6E-6	7.4E-6
Curium	4.1	Cm-244	2.4E+11	4.2E+9	1.3E+6	3.4E-3	4.2E-3	7.4E-5	2.2E-8	5.9E-17
Brine rate with zero threshold thermal gradient(m^3/g)			5.5E-4	4.3E-4	2.7E-4	1.4E-4	5.5E-4	4.3E-4	2.7E-4	1.4E-E

Note: The gross brine inflow rate is 4.3E-4 m^3 per year at 300 years after burial.

(a) Various other solubility data exist, some with higher and some with lower values for various nuclides. These other data may be no more or no less applicable for this preliminary analysis. More specifically, carbon solubility data could be controlled by kinetics and not by equilibrium conditions.

(b) The thorium and neptunium grow larger with time, so that at 10,000 years these inventories are 49.5 and 8,243 grams per package, respectively.

(c) This value is not shown unless the primary (10^{-5}) standard is not met, indicated by a value greater than the one in the preceding column.

Evaluation. For a repository in salt, the expected ground-water effect on the designed engineered-barrier system is corrosion of the waste package by brine in the salt. The effects of this brine are estimated by the following set of calculations (Section 6.4.2.4): (1) the thermal conditions expected to result from the heat-producing waste are calculated; (2) using those thermal conditions and conservative estimates of the amount of brine present in the salt, brine-migration calculations are performed to estimate the amount of brine that will migrate up the thermal gradient to each waste package; and (3) the extent of corrosion expected from this amount of brine is calculated. Brine composition and the effect of radiolysis on brine composition have also been factored into these calculations.

When the brine is assumed to be a high-magnesium (more corrosive) type produced in limited quantities (5.0 volume percent) by halite, clay, and carnallite dehydration, the extent of corrosion is limited by the volume of brine available; waste package lifetime has been calculated to exceed 10,000 years (Section 6.4.2). In the presence of an unlimited volume of a low-magnesium (less corrosive) type intrusion brine, the waste package lifetime is also expected to be greater than 10,000 years. Earlier failure is expected to occur in the event that an unlimited volume of high-magnesium brine contacts the waste package. However, such conditions are unexpected, as a mechanism to produce unlimited volumes of a high-magnesium brine appears to be absent. While magnesium-bearing evaporite minerals (carnallite and kieserite) are present in the upper section of Salt Cycle 6, numerous processes are expected to limit the magnesium concentration of any intrusion brine that flows through the carnallite marker bed on its way to the repository. Any brine flowing rapidly through Salt Cycle 6 will probably not have the opportunity to saturate with magnesium. Although the solubility of carnallite and kieserite are very high (Weast, 1984), a brine intruding into the repository horizon must already be saturated in halite; therefore, the magnesium content of the resultant brine will be limited by its saturation state. The magnesium concentration of the brine will be further attenuated by the precipitation of magnesium-bearing minerals, some of which exhibit decreasing solubility with increasing temperature. Dilution of higher-magnesium fluids by lower-magnesium fluids is also expected to occur. Note that the compositions of the low-magnesium intrusive brines in Table 6-11 are in reasonably good agreement with that of an experimentally produced composite Paradox Basin dissolution brine (Pederson et al., 1984).

It should be emphasized that site-specific brine compositions are not well known at present. Magnesium is one of several constituents that may accelerate corrosion. Corrosion data are presently available at only two magnesium concentrations (Table 6-11), so predictions were made using these values. While site-specific values obtained during site characterization will very likely not match the magnesium contents for which data are available, it is very unlikely that a brine significantly more corrosive than brine A in Table 6-11 can be identified. If information obtained in the future does show that corrosion rates are much higher than those calculated in Section 6.4.2, the repository and waste package will be modified appropriately. If magnesium is determined to be the problem, the corrosion rates could be lowered by placing a magnesium scavenger in the packing surrounding the package. Alternatively, the corrosion allowance around the waste package could be increased, or a more corrosion-resistant material could be used in the waste package design.

The evidence indicates that the potentially adverse condition is not present.

(2) Geochemical processes or conditions that could reduce the sorption of radionuclides or degrade the rock strength.

Evaluation. Halite, anhydrite, carnallite, and kieserite along with low amounts of various other evaporite minerals and clays comprise the dominant mineralogy of the Cycle 6 host horizon (Sections 3.2.7.1, 6.3.1.2.2). The evaporite minerals are not expected to contribute significantly to sorption; clay minerals have stronger sorption capacities, but clay contents in Cycle 6 are very low (Hite, 1983). The Paradox Formation is bounded by clastic strata that are expected to provide sorption capacity; the performance assessment calculations (Section 6.4.2) conservatively assume no sorption. Therefore, further reduction in the assumed sorption capacity is not possible.

Processes that might degrade rock strength include the radiolytic decomposition of mineral phases, thermal dehydration accompanied by volume reduction, and the melting of host rock mineral phases. At high radiation dose rates, halite may decompose to sodium metal colloids, chlorine gas, and other by-products. Such effects have been documented only for radiation fields far exceeding expected conditions at the overpack surface, and the phenomena, when observed, are very localized (Levy and Kierstead, 1982). Clay minerals in the near-field environment will probably undergo dehydration, but clay contents are very low (Hite, 1983). Clay dehydration in the far-field environment will be limited by the lower temperatures (Figures 6-2 and 6-3) to which they are exposed; and any volume reduction accompanying clay dehydration is expected to be offset by salt creep and thermal expansion of the salt strata. The carnallite marker bed is expected to be located at least 9 meters (30 feet) from the repository, and at this distance the maximum temperature to which the carnallite will be exposed is 90 to 120 C (194 to 248 F) (Figures 6-2 and 6-3). In this temperature range, hydrometamorphic reactions such as dehydration and phase transformation are possible; however, melting is not expected. Carnallite begins to dehydrate at 90 C (194 F) and melts at 265 C (509 F) (Conner, 1983; Weast, 1984). Kieserite, which occurs in low quantities in Cycle 6 with the carnallite, begins to both dehydrate and melt at approximately 365 C (689 F) (Conner, 1983). Under hydrous conditions carnallite may undergo phase transformations, but the expected products are minerals with higher melting points (Braitsch, 1971). Brine formation also accompanies the transformation reactions, but the low permeability of Cycle 6 halite suggests that brines resulting from carnallite decomposition or dehydration would probably remain in place and not migrate. If all of the carnallite in upper Cycle 6 salt were to transform to sylvite and brine, the resulting volume increase would be only on the order of 0.31 percent (Section 6.3.1.2.2). If brine were to migrate away from the carnallite beds, the reduction in Cycle 6 volume would be on the order of 1.86 percent.

Section 6.4.2.3.5 presents an evaluation of the extent of the expected "disturbed zone" around a repository in Davis Canyon. These analyses examine the disturbance of the salt by (1) mechanical effects, (2) chemical conditions, (3) thermomechanical conditions, (4) thermohydrologic conditions, and (5) radiation effects. Results of these preliminary analyses indicate that the disturbed zone will not extend a significant distance from the edge of the repository workings, and that decreases in rock strength beyond this narrow zone are not expected. Therefore while the data do not permit definitive conclusions, there is no compelling evidence for geochemical processes that degrade rock strength.

The evidence indicates that the potentially adverse condition is not present.

(3) Pre-waste-emplacement ground-water conditions in the host rock that are chemically oxidizing.

Evaluation. Evidence for the host rock as well as for ground water in the Leadville Limestone underlying the Paradox Formation suggests chemically reducing conditions and consists of the following (Sections 3.2.7.2, 6.3.1.2.2):

- Presence of reduced forms of carbon, iron, and sulfur in Salt Cycle 6 (McCulley et al., 1984; Hite, 1983)
- Cycle 6 methane contents ranging up to 1 cubic centimeter (0.06 cubic inch) gas per kilogram of salt (Hite, 1983, Table 5)
- Insoluble organic carbon contents of Salt Cycle 6 ranging up to 0.5 weight percent (Hite, 1983, Table 2; Padan et al., 1984).
- Presence of organic carbon and pyrite in the clastic sedimentary strata (Hite, 1983, Table 5; Padan et al., 1984; McCulley et al., 1984)
- Presence of methane, ethane, and dissolved sulfide in deep basin brines (Hite, 1983, Table 5; McCulley et al., 1984)

- In situ Eh in deep basin brines ranging from -80 to -240 mV based on platinum electrode measurements and from -113 to -143 mV based on sulfide/sulfate redox couple calculations (McCulley et al., 1984)

- Microbially mediated reduction of sulfate to sulfide is an active, ongoing process (McCulley et al., 1984).

The evidence indicates that the potentially adverse condition is not present.

6.3.1.2.4 Analysis of Disqualifying Condition. This guideline has no disqualifying condition.

6.3.1.2.5 Conclusion for Qualifying Condition. Cycle 6 contains small amounts of brine as fluid inclusions and intergranular brine in halite and as hydration water in clay minerals, carnallite, and kieserite. Corrosion calculations based on deliberately overestimated brine volumes suggest that waste package failure will not occur within thousands of years after repository closure.

Reducing conditions are expected to promote the precipitation of many redox-sensitive radionuclides; others may form insoluble sulfate or carbonate minerals or be adsorbed by clay minerals in either Cycle 6 or in clastic strata above or below the proposed repository horizon. Brine radiolysis reactions have been experimentally documented only at dose rates greatly exceeding those expected at the waste package surface and will be localized to the near-field environment, should they occur.

Preliminary assessments indicate that deep basin brines contain low concentrations of low molecular weight organic acids, which are weak complexing agents. Radiolysis reactions may form additional organic species that are not expected to possess significant complexation characteristics. Radiocolloid formation is expected to be minimized by the destablizing effects of brines.

The host rock can undergo changes resulting from heat and radiation. The hydrous minerals, carnallite and kieserite, may undergo hydrometamorphic transformation reactions to more stable anhydrous phases, such as halite and sylvite; but melting is considered highly unlikely. Halite and anhydrite are expected to be stable at temperatures far above those expected in the near-field repository environment. Adverse effects from radiation are expected to be mitigated by the fact that the expected dose rate at the exterior of the overpack surface is only approximately 20 rads per hour. Preliminary assessments indicate little potential for salt dissolution to affect repository performance in the next 10,000 years.

In conclusion the Davis Canyon bedded salt environment is geochemically conducive to waste isolation should waste package failure occur. Assessments of waste package performance suggest that the engineered-barrier system will contain radionuclides for very long periods of time. This evaluation was conducted using demonstrably conservative assumptions.

The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.3.1.3 Rock Characteristics, Guideline 10 CFR 960.4-2-3

Postclosure rock characteristics are important to the long-term isolation capability of the host rock. The mining operations during repository construction and the heat generated by the emplaced wastes must not cause fractures or the thermal alteration of minerals that would significantly diminish the ability of the site to contain the waste. If extensive changes in the host rock occur, new pathways for radionuclide migration from the repository could result, and the isolation capabilities of the rock could be impaired.

This guideline includes a qualifying condition, two favorable conditions, and three potentially adverse conditions for analysis. It does not have a disqualifying condition.

6.3.1.3.1 Statement of Qualifying Condition.

> The present and expected characteristics of the host rock and surrounding units shall be capable of accommodating the thermal, chemical, mechanical, and radiation stresses expected to be induced by repository construction, operation, and closure and by expected interactions among the waste, host rock, ground water, and engineered components. The characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements set forth in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.

Evaluation Process. To determine whether the Qualifying Condition with respect to the rock characteristics specified in 10 CFR 960.4-2-3 can be met, relevant data are summarized and evaluated. Evaluations are made regarding favorable and potentially adverse conditions at the site. These conditions and findings are summarized in Table 6-10. Conclusions drawn with respect to qualifying the site for further consideration as a potential repository are presented along with a rationale for these conclusions. Cross referencing to other sections of the report is provided.

Relevant Data. Preliminary laboratory test data on the geomechanical properties and indices of Paradox Basin rock units are given in Table 3-5. These data are from rock core taken from the GD-1 borehole. In situ stresses and short-term in situ creep rates were measured in GD-1 in several salt cycles (Section 3.2.6.1). Chemical characteristics of Salt Cycle 6, obtained from core logs, geophysical logs, and petrographic and isotopic analyses of core samples, are discussed in Section 3.2.7.1. Thermal properties of salt and nonsalt rock core samples from GD-1 were tested in the laboratory and data are summarized in Table 3-6. This information comprises the data on which the following evaluations are based.

Assumptions and Data Uncertainty. Most of the available rock characteristics data are from the GD-1 borehole, located 5 kilometers (3 miles) from the site. Rock properties typically vary from one location to another within the same geologic unit; therefore, some uncertainty exists when data are all from tests on rock from a single borehole. Sampling and testing from a site-specific borehole(s) is necessary to decrease the rock properties uncertainties as much as possible. However, the samples from GD-1 appear to provide consistent values of geomechanical rock properties for all the rock types present when compared with measurements of similar rocks elsewhere.

The sampling and testing for geochemical properties from the GD-1 borehole is not sufficient for a statistical evaluation, though useful average percentages and qualitative distribution data are given for the small amounts of mineral and organic impurities found in the salt host rock. In some respects, geochemical characteristics at the actual site are anticipated to be more favorable, with decreased amounts, or the absence of carnallite, kieserite, and sylvite in the salt (Sections 3.2.7 and 3.2.8). The presence of these substances and the organic materials in greater than expected amounts could result in potentially adverse chemical conditions in the repository horizon. However, short-term ambient and elevated-temperature laboratory tests on core samples have not yet revealed any such adverse conditions. Another area of uncertainty lies in the estimation of rock mass properties on the basis of laboratory-tested intact specimens and the character and distribution of rock discontinuity features such as joints, fractures, and bedding planes.

Evaluation of the site against the rock characteristics guideline requires assessment of the response of the host rock and surrounding units to repository construction and the thermal and radiation effects of the emplaced wastes. Available data on rock mass properties is very limited, and no data is available from the site itself. Furthermore, repository design is in a very preliminary stage, and the vertical location of the repository within the host rock has not yet been selected. There is considerable uncertainty associated with rock thermal and mechanical properties at the site due to lack of data. Consequently, elaborate thermomechanical analysis and detailed prediction of the response of the host rock to the imposed loads is not possible at this time. Instead, the analyses presented in the following sections are

highly simplified and generally deal with limiting cases established on the basis of geometric considerations or conservative assumptions of properties. Also, an approach which overestimates risks or adverse impacts has been taken with respect to the evaluations of favorable and potentially adverse conditions.

Because of the lack of site-specific data, uncertainties also exist concerning the thickness of salt above and below the repository. Estimates of the salt-bed thickness and the possible extent of the disturbed zone are uncertain (Section 3.3.2.3 and 6.4.2.3.5).

Analysis. The following analyses of favorable and potentially adverse conditions provide the evaluation relevant to the qualifying conditions.

The host rock, Salt Cycle 6, is estimated to vary between 55 meters (180 feet) and about 65 meters (215 feet) in thickness across the site. Figure 3-19 furthermore indicates that the salt maintains this thickness over a large area. This information is based on core logs, geophysical logs, and the isopach maps derived from them.

Porosity (both primary and secondary) related issues such as the effects of thermal conductivity, thermal expansion and ductility are evaluated. Salt has a higher thermal conductivity than most other types of rock including basalt, shale, and granite. The coefficient of linear thermal expansion of salt ($45 \times 10^{-6}/K$) in the Paradox Basin is greater than that of the overlying rocks. The ductile nature of salt offsets the effects of this high thermal expansion. Creep closure of the backfilled rooms, it is anticipated, will compact the backfill to near its original in situ density and permeability.

Uplift of the overlying strata due to thermal expansion is expected. This expansion could generate tensile stresses in the uppermost strata and thus generate fractures. This uplift has been calculated to be about 1 meter (Loken et al., 1984, Table 7-3) and is distributed gradually over the ground surface. This uplift is not expected to create interconnection between the upper hydrostratigraphic unit and the host rock. The lower water yield and competent character of the rock units above the host rock tend to minimize the deleterious effects of uplift.

Considerations such as rock mass integrity are interpreted to be adequate and as such do not generate concern. It is considered that the strength and integrity of the salt and surrounding rock are sufficient such that existing technology would be satisfactory to ensure waste containment or isolation.

6.3.1.3.2 Analysis of Favorable Conditions.

> (1) A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the underground facility to ensure isolation.

Evaluation. Salt Cycle 6 is the potential repository horizon at the site. In the site vicinity, the thickness of this cycle increases from southwest (upper Salt Creek area) to northeast (Gibson Dome structure). The thickness of Salt Cycle 6 is estimated to vary across the site vicinity from a minimum of approximately 55 meters (180 feet) to a maximum of approximately 65 meters (215 feet) (Figure 3-17, Section 3.2.3.2) The minimum thickness of the salt cycle within the geologic repository operations area must be sufficient to adequately contain the planned, nominal 6-meter (20-foot) high mined storage rooms, emplacement holes, and at least a portion of the zone of disturbed rock surrounding the openings.

To estimate the minimum required thickness of host rock, the dimensions of the following elements are considered: (1) 6 meters (20 feet) of salt beneath the base of the canister hole, (2) the height of the canister hole (6 meters [20 feet]), (3) the room height (6 meters [20 feet]) and, (4) 12 meters (39 feet) of salt cover over the storage room. This latter element is twice the room height in order to accommodate enlarged openings in the roof near shaft stations and any roof strain not predicted by an elastic model. Also, as shown on Figure 3-19 Salt Cycle 6 is at least 60 meters (200 feet) thick over a large area in the site

vicinity. On this basis Salt Cycle 6 is considered to be sufficiently thick and laterally extensive to allow significant flexibility in selecting the repository depth, configuration and location. Based on the above estimate, a recommended minimum salt cycle thickness is assumed to be 30 meters (100 feet). The thickness of Salt Cycle 6 is expected to be approximately 60 meters (200 feet) at the site.

The evidence indicates that the favorable condition is present.

(2) A host rock with a high thermal conductivity, a low coefficient of thermal expansion, or sufficient ductility to seal fractures induced by repository construction, operation, or closure or by interactions among the waste, host rock, ground water, and engineered components.

Evaluation. Thermal conductivity varies as a function of temperature. Tammemagi et al. (1985, ONWI-364, p. 2) give an equation for calculating thermal conductivity in salt. Wang et al. (1983, NUREG/CR-2910, Figure 3.9) compared the thermal conductivities of salt, basalt, shale, and granite and found salt to have generally higher thermal conductivities than the other rock types.

The coefficient of thermal expansion for Paradox Basin is $45 \times 10^{-6}/K$ (Section 3.2.6.2). Lagedrost and Capps (1983, BMI/ONWI-522, Figure 14) found the axial thermal expansion of salt to be higher than that of the rocks in the overlying strata. Additional data on temperatures within the host rock and surrounding units can be found in Section 3.2.6.2.

Rock salt exhibits sufficient ductility (or plasticity) (Lorenz et al., 1981, p. 12) to close and seal fractures, provided it is adequately confined and under sufficient pressure. Elevated temperatures will enhance this attribute of confined salt. The closure-sealing characteristics of confined rock salt under pressure are particularly beneficial in the far field of the planned repository to prevent development of potential flow paths. Furthermore, the closure-sealing behavior associated with the ductility of salt will hasten consolidation of crushed salt that is backfilled into waste emplacement rooms. Consequently, stress states will approach near lithostatic conditions in the salt backfilled rooms and surrounding rock formations. In general, fractures induced in the disturbed zone of the repository will also tend to be closed by salt ductility effects.

Based on the analysis of borehole GD-1 drilling logs and laboratory test data, the salt fabric in the repository host rock is expected to be relatively competent and homogeneous over the total area to be mined (SCC, 1984, p. 3-4). After closure, the creep properties of the salt, discussed in Section 3.2.6.1, will tend to restore in situ conditions in the repository host rock. Based on an analysis of bedded salt with similar creep properties, radial stress buildup on bulkhead seals emplaced in repository openings will reach 50 percent of the initial in situ stress in less than 10 years after closure, whereupon it can be reasonably concluded that any fractures in the salt adjacent to the penetration should be at least significantly closed, if not totally healed, at this stress level (Kelsall et al., 1982, ONWI-405, p. A-30). Creep closure in backfilled waste storage rooms is expected to begin before the repository is sealed (Section 6.4.2.2). It is expected that creep closure will eventually compact the salt backfill to near its original, undisturbed density.

Qualitative predictions of postclosure salt behavior lack precision because of the uncertainties in the salt material model and its parameter values. Qualitatively, however, a characteristic of salt is its ability to undergo large deformations without fracturing in the postclosure stress and temperature environment. This plastic behavior is independent of variations in impurity content for a wide range of distributions and concentrations commonly encountered in evaporite mineralogy. Therefore, although the actual material parameter values are not known with certainty, the physical behavior of salt will reduce the stress concentrations over time and will limit or prevent fracturing.

The evidence indicates that the favorable condition is present.

6.3.1.3.3 Analysis of Potentially Adverse Conditions.

(1) Rock conditions that could require engineering measures beyond reasonably available technology for the construction, operation, and closure of the repository, if such measures are necessary to ensure waste containment or isolation.

Evaluation. No unusual engineering measures are necessary to ensure waste isolation or containment. The competence of the host rock and surrounding rock units is a function of both the intact rock strength and the influence of the rock discontinuities pervading the rock mass. At high-confining stress, which exists at depth, the intact rock strength can have a major influence on rock mass strength. At low-confining stress, near excavated openings or the surface, the rock discontinuities can dominate the performance. At least one of the major rock mass classification systems commonly used for design of subsurface excavations incorporates intact rock strength as one of the rating factors (Bieniawski, 1976).

Comparison of the intact rock strength values given in Table 3-5, to engineering classifications for intact rock (including rock salt) by Deere and Miller (1966) reveals the following:

1. Sandstone and siltstone strata samples range from some very low to low strength samples to a majority of medium to high strength samples, and most are within an average modulus-to-strength ratio band.

2. Limestone strata samples range from medium to high strength samples, and are all generally within the average modulus-to-strength ratio band.

3. Salt data generally plot as a high modulus, low-to-medium strength rock.

The intact rock component of rock mass performance for the host rock and overlying rock units can generally be rated as favorable based on these classifications. The expected performance of the total rock mass can be inferred in part from the rock quality designation (RQD) parameter as logged during drilling, and by a review of in situ stress and water conditions that were tested in the GD-1 borehole.

The RQD is generally high, between 90 and 95 percent, over the first 610 meters (2,000 feet) of overburden depth. Construction, operation and closure aspects for the shafts penetrating these strata should not present any problems. However, approximately one-third of the next 300 meters (985 feet) of drilling down to the repository floor exhibited some high core losses and an average RQD value of 65 through 70 percent, which would classify the rock quality as poor to fair (SCC, 1984, p. 3-3). However, these conditions may have been caused, at least in part, by drilling techniques (WCC, 1982, ONWI-388, Vol. I, p. 34). When drilling procedures were altered, the RQD was between 95 and 100 percent through Salt Cycles 6 and 9. Within the depth interval tentatively characterized by SCC as poor to fair, from approximately 550 to 850 meters (1,805 to 2,789 feet), shaft construction rates could be slowed (SCC, 1984). Good seals behind the shaft liner throughout the last 300 meters (984 feet) of depth will be important to prevent any preclosure or postclosure interaction between the aquifers in the Elephant Canyon member and the salt at repository level. No engineering measures beyond reasonably available technology are expected to be required for any of this work. As noted already, the quality of the salt host rock at repository level is considered good. There is little empirical data concerning the effects of heat on the stability of subsurface tunnels in bedded salt, but this will have a minimal impact on the long-term performance of the repository.

A discussion on the uncertainty concerning the effect of heat on the subsurface tunnels and how this will affect reexcavation and support of the tunnels is given in Section 6.3.3.2.2 (2). While thermomechanical calculations can reasonably predict the amount of room closure and far-field behavior due to creep in the salt host rock, they are not reliable in predicting the response of subsurface tunnels in the early stages of heating. There is also little field evidence to indicate what failure mechanisms are acting immediately around the mine openings

when bedded salt is heated. It appears, however, that the effect of heating will be to exacerbate any tendencies for slabbing and spalling to occur, but it is not known how serious the effect will be on repository performance after backfilling the openings.

Rock salt exhibits sufficient ductility (or plasticity) (Lorenz et al., 1981, p. 12) to close and seal fractures, provided it is adequately confined and under sufficient pressure. Elevated temperatures will enhance this attribute of confined salt. The closure-sealing characteristics of confined rock salt under pressure are particularly beneficial in the far field of the planned repository to prevent development of potential flow paths. Furthermore, the closure-sealing behavior associated with the ductility of salt will hasten consolidation of crushed salt that is backfilled into waste emplacement rooms. Consequently, stress states will approach near lithostatic conditions in the salt backfilled rooms and surrounding rock formations. In general, fractures induced in the disturbed zone of the repository will also tend to be closed by ductility effects.

During decommissioning, the base of any shaft will be filled with concrete. Thereafter the salt sectors will be filled with crushed salt and the nonsalt sections backfilled with dense earthen material. Bulkheads of impermeable material will be constructed at selected intervals during backfilling. Finally the shaft will be capped with concrete (Section 5.1.4.2.2).

Preliminary shaft-seal performance analysis (Section 6.4.2.3.5) indicates that groundwater flow through and around the shaft will probably be very small. A combination of both shaft and repository seals will reduce even further the likelihood of any ground water reaching the waste, thus ensuring isolation.

The evidence indicates that the potentially adverse condition is not present.

> (2) Potential for such phenomena as thermally induced fractures, the hydration or dehydration of mineral components, brine migration, or other physical, chemical, or radiation-related phenomena that could be expected to affect waste containment or isolation.

Evaluation. Thermal fracturing is generally characterized as thermal decrepitation. This destructive mechanism is discussed in Section 3.1.2.6.2. Laboratory tests on selected core samples show that Paradox salt has been heated to 450 C (844 F) without decrepitation effects (Senseny, 1982, ONWI-9[82-4], p. 155; Lagedrost and Capps, 1983, BMI/ONWI-522), and this temperature is well above the maximum allowable design temperature of 250 C (482 F) for the repository salt. The formation of fractures due to thermal uplift, as discussed under the next condition, is not expected to affect waste containment or isolation.

Anhydrite and other insoluble minerals average only 4 to 5 weight percent, making the Paradox salt relatively pure. Salt Cycle 6 contains the carnallite marker bed. Other nonsalt components of Salt Cycle 6 include organic carbon contents ranging from 0.05 to 0.51 percent, which is high relative to most other salt deposits.

Based on the limited amount of data available, the potential for deleterious effects in host rock properties caused by thermal dehydration of carnallite minerals or organic content present in Salt Cycle 6 is not apparent, as discussed in Section 3.2.7.1. and Section 5.2.1.

It is well established, both by experiment and theory, that liquid-filled brine inclusions within salt crystals migrate up a temperature gradient in the salt, and that the maximum migration rates that will occur within crystals in a repository can be estimated with reasonable confidence (Jenks and Claiborne, 1981, ORNL-5818, p. 1). Direct measurements by Bradshaw and McClain (1971, ORNL-4555) at Project Salt Vault project approximately 2 to 10 liters (approximately 2 to 11 quarts) of brine accumulation per emplacement hole after approximately 20 to 30 years (Carter and Hansen, 1983, p. 317), the rate of accumulation approaching zero at that time. This projection is compatible with modeling predictions of Jenks and Claiborne (1981, ORNL-5818, p. 115). Such rates can be tolerated in a waste repository (Bradshaw and McClain, 1971, ORNL-4555). Direct brine migration rates have not yet been measured for

Paradox salt, but they are expected to be similar to the calculated values of 25 and 8 liters (approximately 26 and 8 quarts) in 100 years, for commercial high-level waste (CHLW) and spent fuel (SF), respectively, as predicted by Jenks and Claiborne (1981, ORNL-5818 p. 115) for bedded salt. The presence of brine is expected to cause some corrosion of the waste canister, but the wall thickness of the canister can be increased easily to accommodate the loss.

In tests of bedded salt samples from the Carey Mine in Kansas, the compressive strength of the salt exposed to 5×10^8 roentgen was approximately 10 to 20 percent less than for unirradiated salt, and the modulus of elasticity was greater than for unirradiated samples (Bradshaw et al., 1968). Such changes are not expected to cause any major difficulties for the design of a repository (Bradshaw and McClain, 1971, ORNL-4555, pp. 7-10).

From the preceeding discussion, it is concluded that this potentially adverse condition exists principally because significant uncertainties exist regarding the potential deleterious effects on waste containment or isolation that could be caused by thermal dehydration of carnallite and organic minerals, and the potential effects of brine migration.

The evidence indicates that the potentially adverse condition is present.

> (3) A combination of geologic structure, geochemical and thermal properties, and hydrologic conditions in the host rock and surrounding units such that the heat generated by the waste could significantly decrease the isolation provided by the host rock as compared with pre-waste-emplacement conditions.

Evaluation. A known potentially disruptive mechanism to isolation that considers all of the elements of the above condition is the thermal uplift expected as a result of waste heat generation. Thermal uplift can cause tensile stresses to develop in the uppermost strata overlying the repository, and may result in opening of existing fractures in these strata. This fracturing could increase the potential for interaction between ground-water-bearing zones in the upper hydrostratigraphic unit and the host rock. Convection cells or buoyancy effects caused by the heat produce circulation systems that may introduce dissolution conditions in the host rock and shorten waste migration pathways. In addition to analysis of the waste isolation integrity of the overburden that results from thermal uplift, the surface effects of this uplift need to be considered.

The rock mass properties of the strata overlying the repository are pertinent to this analysis. The RQD is between 90 and 95 percent over the first 610 meters (2,000 feet) of depth. Considering this evidence, other drilling performance parameters, and the laboratory data, it is expected that the rock mass quality should be good over this interval. The only aquifers of note encountered in GD-1 occur within the upper 365 meters (1,200 feet), and these are expected to yield approximately 2.8×10^{-3} cubic meters per second (43 gallons per minute) to a 3.6-meter (12-foot) diameter shaft (WCC, 1982, ONWI-290, Vol. II, p. 9-17). Conditions at the geologic repository operations area are expected to be similar to those of GD-1. The low water yield and the generally competent character of rock units above the host rock are considered favorable conditions with regard to this potentially disruptive mechanism.

Repository scale thermomechanical analyses by the DOE (1981, DOE/NWTS-147[2]) and Russell (1979) show that vertical uplift, caused by heating of the repository, could be as much as 3 meters (9.8 feet) and not cause isolation concerns. For example, Loken et al. (1984, Table 7-3) calculated a maximum surface uplift of 1 meter (3.3 feet). This uplift is distributed gradually over the ground surface above the repository. This 1 meter does not represent a differential movement over a short distance that would cause significant shear distortion and cracking of the overburden. The finite element model used by Loken et al. (1984) accounted for stratigraphic heterogeneities of thermomechanical properties for repository region formations. They ignored discontinuities such as joints and fissures not only because of a lack of data, but also because their omission would overpredict the thermomechanical response. Their calculations overpredict the thermomechanical response in another way. Because they made an elastic calculation, any stress relief due to creep closure of repository excavations and compaction of room backfill was ignored. Disregarding that, much of the

stress driving uplift would dissipate in the creep closure of the repository rooms and consolidation of crushed salt backfill. Based on the above analyses and discussion, it is not expected that thermal uplift will significantly reduce the isolation characteristics of the host rock.

The evidence indicates that the potentially adverse condition is not present.

6.3.1.3.4 Analysis of Disqualifying Condition. This guideline does not have a disqualifying condition.

6.3.1.3.5 Conclusion for the Qualifying Condition. The requirements of the qualifying condition of the guideline (960.4-2-3) are that the present and expected characteristics of the host rock and the surrounding units shall be capable of accommodating the thermal, chemical, mechanical, and radiation stresses expected to be induced by repository construction, operation, and closure, and by expected interaction among the waste, host rock, ground water and engineered components, such that specifications given in 10 CFR 960.4-1 and 10 CFR 60.113 are met.

The specifications state that the geologic repository shall consist of a system of natural and engineered barriers that will physically separate the radionuclide waste from the accessible environment after closure in accordance with 10 CFR Part 60 and 40 CFR Part 191.

The natural barrier characteristics of the host rock, in depth, thickness, and lateral extent have been described, as well as the expected thermomechanical interactions between the host rock and surrounding units relative to maintaining the specified level of waste isolation standards. Favorable conditions were found for thickness and lateral extent of the host rock, and the thermal properties and thermomechanical performance of the combined natural barrier system in maintaining waste isolation. No potentially adverse conditions or needs for unusual engineering measures to maintain isolation, or conditions of thermal decrepitation, dehydration of minerals, brine migrations or other phenomena, or combinations of geologic structure, geochemical, and thermal properties and hydrologic conditions in the host rock or surrounding units that could lead to significant loss of isolation as a consequence of waste heat generation were found. One potentially adverse condition was found in that dehydration of mineral constituents and migration of brine to the canister could affect waste isolation.

The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.3.1.4 Climatic Changes, Guideline 10 CFR 960.4-2-4

Climatic changes could, over time, alter the geohydrologic system at a site. The guideline for postclosure climatic changes focuses on changes that may favorably or unfavorably affect the ability of a repository to isolate waste after closure. Sites at which projected climatic conditions will not be likely to affect radionuclide releases would be preferred over sites at which those conditions could affect releases.

This guideline includes a qualifying condition, two favorable conditions, and two potentially adverse conditions for analysis. It does not have a disqualifying condition.

6.3.1.4.1 Statement of Qualifying Condition.

> The site shall be located where future climatic conditions will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1. In predicting the likely future climatic conditions at a site, the DOE will consider the global, regional, and site climatic patterns during the Quaternary Period, considering the geomorphic evidence of the climatic conditions in the geologic setting.

Evaluation Process. The prediction of future climatic conditions at the site is based on the premise that climatic changes that occur in the future will be comparable to those that have occurred during the recent geologic past, the Quaternary Period, which is defined in the guidelines as the last two to three million years. Interpretation of Quaternary climatic variations is derived from the geologic and biologic record, from which both a long-term averaged effect, and sometimes a maximum or minimum bounding factor, can be extrapolated. Global data define the cyclic nature and comparative intensities of Quaternary glaciations, whereas regional and local data indicate the magnitude of climatic variations that may characterize future conditions at the site. Local assessments are based on fluvial deposits linked to glacial cycles, pedologic studies, and analysis of pollen and vegetation debris that are found in pack-rat middens.

Similarly, any potential change in subsurface hydrologic parameters or dissolution potential caused by future climatic variations, including dissolution, should be comparable to hydrologic changes that occurred periodically during the Quaternary Period. This assessment is based on the assumption that future climatic changes will be comparable to those that have occurred in the past. Subsurface geologic data were examined to assess whether changes in climate resulted in increases in hydrologic flow rates as evidenced in the lithologic record of the Paradox Formation. The evaluations and the findings are summarized in Table 6-10.

Relevant Data. This analysis includes several primary sources of information. The first considers global climatic changes. Pronounced, regular climatic fluctuations between glacial and interglacial conditions during the last 1 million years have been recognized in deep-sea cores (Bowen, 1978, Table 10-1; Imbrie and Imbrie, 1979, Figure 39). However, global data provide no evidence that climates during the early or middle part of this sequence were more severe than those associated with the later cycles (Meierding and Birkeland, 1980, p. 167). Therefore, the more accessible, better preserved geologic and biologic data of the most recent glacial episodes can be used to reconstruct climatic conditions that can be considered representative of previous periods of climatic cooling. Many paleoclimatic reconstructions are, therefore, based on data from the last full glacial maximum, termed the late Pleistocene or late Wisconsin, which extended from approximately 21,000 to 15,000 years before present (BP) (Spaulding et al., 1983, p. 263).

The present Holocene age, defined as approximately the last 10,000 years (Imbrie and Imbrie, 1979, p. 178), is representative of climatic conditions that define the other extreme of the climatic cycle, the interglacial. Global temperatures reached a maximum during the Holocene, approximately 7,000 years ago, when they were approximately 8 C (12 F) warmer than ice-age levels, and approximately 2 C (3.5 F) warmer than they are at present (Imbrie and Imbrie, 1979, pp. 178-179). However, peak temperatures during the interglacial at Isotope Stage 5e (128,000 to 118,000 years ago [Bowen, 1978, Table 10-1]) may have been 1 to 2 C (2 to 3.5 F) warmer than the highest Holocene temperatures (Imbrie and Imbrie, 1979, Figure 48).

A second primary source of information consists of regional data. Global climatic patterns are represented in the western United States by the cyclic pattern of glacial deposition that is observed throughout high mountainous regions. The evidence and extent of multiple Quaternary glaciations in southeastern Utah is described in Section 3.2.2.3. In summary, evidence of glaciation has been observed only in the La Sal Mountains, where the lowest elevation reached by glacial ice was approximately 2,010 meters (6,600 feet), and the maximum glacier length was 14.5 kilometers (9 miles). At their closest point, the La Sal glaciers were 45 kilometers (28 miles) from the site (Richmond, 1962, Plate 1), which is at an elevation of approximately 1,567 meters (5,140 feet). Only periglacial features have been observed in the Abajo Mountains, 35 kilometers (22 miles) south of the site.

Late Wisconsinan climate in the Southwest, described in Section 3.2.2.3, was characterized by greater effective moisture, and mean annual temperatures that may have been approximately 10 C (18 F) cooler than at present. The end of late Wisconsinan climatic conditions, as seen in pluvial lake and vegetation records, occurred at approximately 11,000 years BP, although the transition to Holocene climates was gradual, and at various locations occurred between approximately 15,000 and 7,800 years BP (Spaulding et al., 1983, p. 263).

A third primary source of information is local paleovegetation data. Pollen and vegetational debris found in fossil pack rat middens have been used to interpret local paleoclimatic conditions throughout the Southwest, and a preliminary study has been completed near Davis Canyon (Betancourt, 1984; Betancourt and Biggar, 1985, BMI/ONWI-570). Two sequences of middens that span the last 13,000 years have been sampled on the south side of the Abajo Mountains, 30 and 80 kilometers (20 and 50 miles) south of the site. Latest Wisconsinan climatic parameters interpreted from the macrofossil data in these middens (summarized from Section 3.2.2.3) indicate a 4 C (7 F), and not more than 5 C (9 F), lower mean annual temperature than present-day values (Betancourt and Biggar, 1985, BMI/ONWI-570, Table 4-1, p. 64). Mean annual precipitation values 13,000 to 11,000 years ago may have exceeded present amounts by as much as 114 percent. Therefore, annual precipitation may have been as great as 46 centimeters (18 inches) at the site, which now has an annual average precipitation of approximately 21.3 centimeters (8.4 inches) (Section 3.4.3.3).

During Holocene time, temperatures increased and precipitation shifted from a winter-to summer-dominant rainfall, relative to latest Wisconsinan conditions. The middle Holocene was characterized by a warm moist climate. This assessment is based on the apparent local and regional increase in abundance of Gambel oak, whose northward expansion would be favored by increased summer rains, combined with a reduction of spring freezes (Betancourt, 1984; Betancourt and Biggar, 1985, BMI/ONWI-570, pp. 73-74; Neilson and Wullstein, 1983).

A fourth source of information consists of geomorphologic and surficial geologic data from the site. The topographic position, occurrence, and texture of surficial geologic deposits can be attributed to Quaternary climatic changes and extremes, and can provide insight into the extent to which geomorphic and dissolution processes may be affected by future climatic changes. Regional data, as well as data from Indian Creek, which is north and east of the site and drains the Abajo Mountains, have been collected and examined. During glacial stages, Indian Creek transported and deposited gravel-sized clast. Streambed incision probably occurred during a part of the glacial cycle when discharge was high and sediment load was low (WCC, 1982, ONWI-290, Vol. I, pp. 3-8 to 3-9). Based on calcic soil development, terraces that are approximately 32 meters (105 feet) above present stream level may have formed approximately 135,000 years ago (or earlier) (Table 3-2; WCC, 1982, ONWI-290, Vol. II, pp. 4-8 to 4-9), the beginning of the Isotope Stage 5e interglacial stage. A lower terrace at 20 meters (26 feet) above present stream level was probably formed during the early stage of the more recent glaciation, or around 75,000 years before present (Imbrie and Imbrie, 1979, p. 186). A maximum incision rate for glacial stage streams calculated from the topographic position and minimum estimated age difference between these two sets of Indian Creek terraces is 0.2 meter (0.7 foot) per 1,000 years, which is comparable to the long-term incision rate calculated for the Colorado Plateau (Sections 3.2.2.2 and 6.3.1.5). Comparable studies on terraces of similar age on Pack Creek, near Moab, resulted in estimated maximum incision rates of 0.4 meter (1.2 feet) per 1,000 years (Table 3-2).

The other climatic extreme, the warm, dry conditions of an interglacial, is represented by unconsolidated, fine-grained fluvial and eolian deposits that are Holocene in age, and occur throughout the site and vicinity (WCC, 1982, ONWI-290, Vol. II, Figure 4-1). Radiocarbon dates of up to 10,000 years BP have been derived from the fluvial deposits that occur as fill within the bedrock channel rather than on strath terraces above the present channel. Periodic flushing of fine-grained stream channel deposits, and subsequent refilling of the bedrock channel, has occurred during Holocene time, as indicated by cut-and-fill structures observed in streambank exposures. However, little to no evidence of significant bedrock incision during Holocene time was observed in the vicinity of the proposed site, and the rate at which streams downcut into bedrock during the last 10,000 years is almost imperceptible. It appears that the long-term bedrock incision rate of approximately 0.24 meter (0.8 foot) per 1,000 years (Section 6.3.1.5) does not reflect the rate at which bedrock incision occurs under interglacial climate conditions.

A fifth primary source of information is calcic soils. The preservation of calcic soils on Quaternary deposits of varying ages throughout the Paradox Basin is indicative of a prevalent arid and semi-arid climate for at least the last 0.5 million and possibly 2 million years. Preservation of the calcium carbonate in these soils makes it unlikely that

precipitation exceeded 50 to 70 centimeters (20 to 25 inches) for any significant period of time during the Quaternary period (Section 3.2.2.3).

As described in Section 3.2.2.4, Richmond's (1962) studies of Quaternary deposits and soils in the La Sal Mountains, near Moab, provide an indication of the relationship between soil carbonate and precipitation in southeastern Utah. Prominent calcic soils are currently observed below 1,980 meters (6,200 feet) where annual rainfall is estimated at 27.2 centimeters (10.1 inches) (Betancourt and Biggar, BMI/ONWI-570, 1985, p. 25). These soils also survived pluvial glacial periods without visible evidence of leaching and carbonate erosion. During the cooler, wetter Late Pleistocene, the minimum elevational depression of alpine and montane plant species on the southern flank of the Abajo Mountains was 700 to 850 meters (2,300 to 2,800 feet) (Betancourt and Biggar, 1985, BMI/ONWI-570, p. 77). Therefore, calcic soils, observed today at 1,890 meters (6,200 feet) in the La Sals, could have been subject to precipitation amounts which occur today at elevations of 2,590 to 2,740 meters (8,500 to 9,000 feet). Current precipitation at these higher elevations is 58.1 centimeters (22.9 inches) to 67.7 centimeters (26.7 inches). These observations support the theory that precipitation in the site vicinity did not exceed 50 to 70 centimeters (20 to 27.5 inches) during Quaternary time.

A sixth primary source of information is hydrogeologic data. The repository host rocks occur below the ground-water table. Diagenetic changes in the Paradox Formation, evidenced in the GD-1 core, have resulted in essentially total occlusion of porosity in the evaporite strata section (Section 3.2.7.1). Stability of the intrinsic hydrologic characteristics (porosity and permeability) of the rocks in the upper hydrostratigraphic unit (above the salt) is also indicated during and prior to the Quaternary Period by the diagenetic products in pore space of GD-1 core samples (McCulley et al., 1984, p. 24). Laboratory tests on the host rock indicate that its porosity and permeability are effectively zero (Section 3.3.2.2). Geophysical logs of drill holes near the site and the core from GD-1, show no evidence that dissolution has occurred in the Paradox Formation since deposition of the evaporite sequence (Section 6.3.1.6). Mineralogic composition and depositional features in the salt indicate essentially no influx of water into the potential host rock since diagenesis of the Paradox Formation (Section 3.2.3.3).

Assumptions and Data Uncertainties. Three assumptions are included in the assessment of future climatic changes. The first is the human influence on future climatic changes. The primary assumption is that during the next 100,000 years climatic conditions will return to those that characterized the Pleistocene glacial periods. However, industrialization and the resultant increase of carbon dioxide, and other trace gases, in the atmosphere may disrupt the cyclic pattern that has characterized the climatic fluctuations of the Quaternary period (Schneider and Temkin, 1977, pp. 30-32; Imbrie and Imbrie, 1979, pp. 184-187; Schneider and Londer, 1984, pp. 307-348).

The principal concern is the effect of the addition of carbon dioxide to the earth's atmosphere through the burning of fossil fuels. As the carbon dioxide content of the atmosphere increases, there is an increase in the atmospheric absorption and emission of terrestrial infrared radiation (the greenhouse effect), resulting in the warming of the lower atmosphere and cooling of the stratosphere (Schneider and Londer, 1984, p. 346). Imbrie and Imbrie (1979, p. 185) referred to the resulting warm period as the "super-interglacial age" because projected global temperatures are approximately 1.7 C (3 F) higher than those postulated for any previous interglacial periods, or the present one. These authors speculate that the superinterglacial effect would last approximately 2,000 years, after which time the long-term cooling cycle, driven by changes in the earth's orbit, would reassert itself. Basically, the greenhouse effect, predicted from an increase of carbon dioxide and aerosols in the atmosphere, would delay the initiation of global cooling, but would not be a long-term effect interfering with the character, timing, and recurrence of the next full glacial period, which is postulated as beginning approximately 23,000 years from now (Imbrie and Imbrie, 1979, p. 186-187).

A second assumption concerns continuity of the subsurface strata. The assessment of the impact of climatic change on the hydrologic system of the repository horizon assumes that the

repository layer(s) at the site is laterally extensive and comparable to the correlative stratum encountered in the nearby drillholes (Section 3.2.3.3).

The third assumption regards the use of pack rat midden data to reconstruct paleoclimates. Pack rats construct their middens from materials they can forage within 100 meters (300 feet) of their dwellings (Betancourt and Biggar, 1985, BMI/ONWI-570, p. 1). Because fossil pack rat middens are commonly found along rocky escarpments that could have been a local refugium for plants, specific plants that appear as abundant in midden debris may be a local phenomenon that is not indicative of the vegetational community of the area. Elevational analogs used in midden analysis may, therefore, overestimate the amount of climate change represented by the vegetation debris if pollen data, which are representative of a much broader area, are not simultaneously examined (King and Van Devender, 1977, p. 203).

Elevational analogs used to reconstruct paleoclimate at a midden site assume that mean annual precipitation and temperature are the controlling factors in determining plant distribution (Spaulding et al., 1983, p. 272). Actually, the presence (or lack) of competitive species may control the elevational range of some plants, and their present distribution may be different than what it was during Wisconsinan time for that reason (Betancourt and Biggar, 1985, BMI/ONWI-570, p. 118).

Similarly, plant associations are also commonly assumed to be constant from Wisconsinan to present time. However, plant species respond individually to external forcing factors, so during periods of significant climatic change, associations would be varied as the plant community adjusts itself to new conditions. As data for the Southwest accumulate, it is becoming apparent that major vegetation zones at 18,000 years before present may not have direct equivalents in the modern vegetation growing nearby at higher elevations (Cole, 1982). Therefore, recent interpretive studies tend to focus on the dynamics of individual plant species, particularly those that have been found to have unique distributional behavior (Spaulding et al., 1983, pp. 272-276).

Analysis. The evaluation used to show compliance with the requirements of the Technical Guideline involves (1) the analysis of the quality of data used to reconstruct paleoclimates, (2) the identification of geologic and hydrologic processes that could be affected by climatic change and that are significant to containment of radionuclides, and (3) an assessment of the effect that climatic change would have on the rates at which these processes are operating.

Data quality was assessed through the comparison of paleoclimatic reconstructions derived by various means. Qualitative paleoclimatic reconstructions are derived from the geologic and pedologic data, whereas the paleovegetational data collected from fossil pack rat middens can provide a quantitative value for former temperatures and precipitation. In the data evaluation, the results derived using the two different approaches were found to be compatible and reasonable. In addition, they are also comparable with findings from similar studies conducted elsewhere in the Southwest (Spaulding et al., 1983; Spaulding, 1983).

The geologic and hydrologic processes that may be affected by climatic change and are significant to siting are (1) stream incision during periods of high discharge of a glacial stage, (2) dissolution of the repository rock resulting from increased ground-water flow through the host rock, as a result of glaciation, and (3) the rate at which dissolution is occurring.

The rate of stream incision calculated in the preceeding section for the time period bracketed by Indian Creek fluvial terraces of Bull Lake- and Pinedale-equivalent glacial stages is a maximum of 0.2 meter (0.7 foot) per 1,000 years. This rate is comparable to the long-term average rate of stream incision, which is approximately 0.24 meter (0.8 foot) or less, calculated for the Colorado Plateau (Section 6.3.1.5). These data indicate a possible but small increase in the rate at which stream incision occurs during glacial cycles. Such a change may be expected as stream flow increased due to an increase in precipitation, but bedload had not yet increased (Sinnock, 1978, p. 176; WCC, 1982, ONWI-290, Vol. I, Figure 3-10). However, the terrace data indicate that any short-term increase in incision rate is not significant to the safety of a repository constructed at a depth of approximately 885 meters (2,900 feet) (Section 6.3.1.5).

Essentially no data are available on changes in hydraulic gradient caused by past climatic variations. However, by making the simple worst-case assumption that future precipitation rates increase to the point where the water table reaches ground surface in the Abajo Mountains, the resultant hydraulic gradient between there and the Colorado River is not significantly greater than the present maximum apparent hydraulic gradient estimated from GD-1 hydrologic tests.

The effect of climatic change on the rate of hydrologic flow through the repository host rock was evaluated to be negligible because of the lack of evidence that flow parameters had changed in Pleistocene time. A change of any significance to waste containment by the host rock during previous glacial cycles would have resulted in indications that dissolution of the evaporatic strata, or at least some evidence of ground-water flow through the evaporites, had occurred. This evidence has not been observed in subsurface data available in the vicinity of the site (Sections 3.3.2.2 and 6.3.1.6). The effect of climatic change on intrinsic porosity and permeability of the rocks above the salt also seems to be small, based on petrographic examination of GD-1 core and an evaluation of diagenetic products (McCulley et al., 1984, p. 24).

Data are not presently available regarding the effect of climatic change on the occurrence or rate of dissolution. Areas where geomorphic and stratigraphic evidence indicate that dissolution has occurred or is suspected to have occurred are discussed in Sections 3.2.5.6 and 6.3.1.6. As stated in these sections, the closest feature that may be due to dissolution is 14.5 kilometers (9 miles) from the site. At distances closer to the site, no Quaternary deposits or deformation that may be indicative of dissolution have yet been recognized.

6.3.1.4.2 Analysis of Favorable Conditions.

(1) A surface-water system such that expected climatic cycles over the next 100,000 years would not adversely affect waste isolation.

Evaluation. For this evaluation, an increase in the rate of incision of the surface water system is considered to be the principal adverse effect that would result from expected climatic changes over the next 100,000 years. As discussed above, an increase in incision rate might be expected during glacial conditions such as those known to have occurred during the Quaternary Period in the geologic setting. Using a maximum rate of incision of approximately 0.4 meter (1.2 feet) per 1,000 years as the rate of bedrock incision during a glacial cycle, streams in the site may incise approximately 40 meters (132 feet) into the present bedrock surface during the next 100,000 years (Section 6.3.1.4.2). This process will not affect the integrity of a repository developed at a depth of approximately 885 meters (2,900 feet).

The evidence indicates that the favorable condition is present.

(2) A geologic setting in which climatic changes have had little effect on the hydrologic system throughout the Quaternary period.

Evaluation. In this evaluation, change in recharge to the hydrologic system is considered to be the principal effect that may result from climatic change. Climatic changes during Quaternary time are interpreted to have increased precipitation by as much as 120 percent. Hence, the recharge to the subsurface hydrologic system should have increased and, as a result, the rate of flow through subsurface hydrostratigraphic units, as well as the potential for host rock dissolution, may have been increased.

It is uncertain to what degree these changes affected the hydrologic system. However, it does not appear that changes of a similar magnitude would adversely affect the waste isolation capabilities of the site, if they were to occur in the future. As discussed in Section 6.3.1.4.2, past climate fluctuations are not known to have altered intrinsic porosity and permeability. Increased recharge in the Abajo Mountains would also not significantly change the hydraulic gradient over existing values.

Examination of geophysical logs of drillholes in the site vicinity indicates that no dissolution has occurred in the salt sequence penetrated by these boreholes (Section 6.3.1.6). Therefore, the site is located in an area in which the available data indicate that dissolution, as a result of climatic changes, has not occurred during the Quaternary period. If dissolution had occurred during Quaternary time, it would have likely occurred along more susceptible geologic structures at distances greater than 14.5 kilometers (9 miles) from the site (Section 6.3.1.6). However, data are not available to assess whether this dissolution has been ongoing, was affected by climate changes during Quaternary time, or whether the rate of dissolution, if it has been occurring during Quaternary time, has been affected by Pleistocene climatic changes.

The above evaluation suggests that Quaternary climatic changes do not appear to have had a significant observable effect on the hydrologic system. However, the phrase "little effect" in the favorable condition statement has been taken to mean "measureable changes." On the basis of existing information, it is not possible to state that no measureable changes occurred in the hydrologic system as the result of Quaternary climatic changes.

The evidence indicates that the favorable condition is not present.

6.3.1.4.3 Analysis of Potentially Adverse Condition.

> (1) Evidence that the water table could rise sufficiently over the next 10,000 years to saturate the underground facility in a previously unsaturated host rock.

Evaluation. This condition is not applicable to the site because the host rock is already below the water table.

The evidence indicates that the potentially adverse condition is not applicable.

> (2) Evidence that climatic changes over the next 10,000 years could cause perturbations in the hydraulic gradient, the hydraulic conductivity, the effective porosity, or the ground-water flux through the host rock and the surrounding geohydrologic units, sufficient to significantly increase the transport of radionuclides to the accessible environment.

Evaluation. Although discharge of surface streams was higher than at present during glacial periods, as indicated by the size of cobbles in Pleistocene stream gravels, no effects on the hydrogeologic character of the host rock for the repository have been observed. Laboratory tests on the host rock indicate that its porosity and permeability are effectively zero (Section 3.3.2.2). Therefore, essentially no movement of ground water exists through the proposed repository rock. This condition is not expected to change during future climatic changes because several climatic changes of comparable magnitude to projected future variations have occurred in the geologic past. No evidence has been seen in geophysical logs of nearby boreholes, or during geologic inspection of the GD-1 core, of an influx of external ground water into Salt Cycle 6 since diagenesis of the salt deposits in Pennsylvanian time (Section 3.3.2.1).

As discussed in Section 6.3.1.4.2, core data from the GD-1 borehole show no evidence of changes in intrinsic porosity and permeability in the rocks of the upper and lower hydrostratigraphic units resulting from climate changes during glacial periods.

Increased recharge in the Abajo Mountains would also not significantly affect the hydraulic gradient in these units. The potential effect of an increase of precipitation on the hydrologic system is discussed in Section 6.3.1.4.1. Using the hydrogeologic characteristics of the Upper Hydrostratigraphic Unit, as presented in Section 3.3.2, a simple worst case assumption was made, in which future precipitation rates increased to the point where the water table reached ground surface in the Abajo Mountains. The resultant hydraulic gradient between the Abajo Mountains and the Colorado River is not significantly greater than the present maximum apparent hydraulic gradient estimated from GD-1 hydrologic tests.

The evidence indicates that the potentially adverse condition is not present.

6.3.1.4.4 Analysis of Disqualifying Condition. The climatic changes guideline does not have a disqualifying condition.

6.3.1.4.5 Conclusion for the Qualifying Condition. The requirements of the qualifying conditions of this guideline are that climatic changes will not lead to radionuclide releases greater than those allowed under the requirements of 10 CFR 960.4-1, or specifically, that releases meet the requirements of 10 CFR Part 60 and 40 CFR Part 191.

The magnitude of climatic change that can be expected to occur in the future is expected to be comparable to the climate that was estimated to have characterized the late Quaternary Period. In response to climates of a glacial stage, the surface hydrologic system may incise stream channels into bedrock at a rate that is slightly higher than the long-term average discussed in Section 6.3.1.5. However, this more rapid rate of incision would not lead to an increase in radionuclide releases during the time period specified in Section 6.3.1.5, because the stream incision would not approach within 610 meters (2,000 feet) of the repository (Section 6.3.1.5).

No evidence that the subsurface hydrologic system has been influenced by climatic changes during the Quaternary Period has been observed in surficial geologic deposits or geomorphic features in the site or in available subsurface hydrologic, hydrochemical, or geophysical data within the site (Section 6.3.1.4.2). These data indicate that if dissolution is occurring in proximity to geologic structures that extend from the ground surface to (or through) the Paradox Formation, and are a minimum of 14.5 kilometers (9 miles) from the site, the dissolution front has not extended as far as the data points near the site, nor has it affected the ground surface.

The above data demonstrate that compliance with conditions specified in 10 CFR Part 60 and 40 CFR Part 191, which refer to acceptable release of radionuclides to the accessible environment, can be maintained during future climatic changes. Climatic variations that may occur during the lifetime of the repository are projected from climatic changes that have occurred during the Quaternary period, and are expected to be of comparable magnitude.

The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.3.1.5 Erosion, Guideline 10 CFR 960.4-2-5

The objective of the Technical Guideline on erosion is to ensure that erosional processes will not degrade the waste-isolation capabilities of a site. In evaluating the potential effects of erosion on waste isolation, the depth of the host rock is most important. The site should allow the underground facility to be placed at a depth sufficient to ensure that the repository will not be uncovered or otherwise adversely affected. The disqualifying condition in the guideline on erosion states that the minimum depth is 200 meters (656 feet); a depth of at least 300 meters (984 feet) is a favorable condition.

This guideline includes a qualifying condition, three favorable conditions, and two potentially adverse conditions for analysis. It also has one disqualifying condition.

6.3.1.5.1 Statement of Qualifying Condition.

> The site shall allow the underground facility to be placed at a depth such that erosional processes acting upon the surface will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1. In predicting the likelihood of potentially disruptive erosional processes, the DOE will consider the climatic, tectonic, and geomorphic evidence of rates and patterns of erosion in the geologic setting during the Quaternary Period.

Evaluation Process. Rates of erosion for the Quaternary period are calculated from data available for the site and vicinity, and are compared with those derived for a more extensive area of the Colorado Plateau tectonic province. Long-term rates of incision, based primarily on geomorphic data, can also be compared with rates calculated from incised features interpreted to be climate-related. The depth to which erosion may occur, using the maximum of the calculated rates of incision, is then compared with the actual depth of waste emplacement to assess the potential for erosion to cause radionuclide releases that are in excess of those allowable under the specifications of 10 CFR 960.4-1. The evaluations and findings are summarized in Table 6-10.

Relevant Data. This analysis includes several data sources. The first source is depth to the proposed repository horizon. The proposed salt horizon for repository development is Salt Cycle 6, which occurs at a depth of approximately 885 meters (2,900 feet) (McCleary and Romie, 1985, Figures 4-6 and 4-7). Derived depths to the proposed repository horizon are based on available nearby well data. This horizon is penetrated by GD-1, a DOE well located 5 kilometers (3 miles) northeast of the site; a Gulf Oil Corporation well, 11.2 kilometers (7 miles) to the east; and a Pure Oil Company well, 11.2 kilometers (7 miles) to the northwest. The Champlin Petroleum Company well, 8.8 kilometers (5.5 miles) southeast of the site, penetrated the top of the Paradox Formation but did not extend down into Salt Cycle 6. The closest data point to the southwest is the Occidental Petroleum Corporation Well No. 2 in Beef Basin, 22 kilometers (13.5 miles) from the site (McCleary and Romie, 1985, Figures 1-1, 4-7, and A-28).

The second information source is the calculated rate of river incision in the vicinity of the geologic repository area, and the derivation of these data. Throughout Quaternary time the Colorado River and its tributaries have been downcutting through the sedimentary bedrock strata of southeastern Utah in response to regional uplift of the Colorado Plateau that began approximately 10 million years before the present (BP) (Section 3.2.5.4). The long-term incision rate for the larger perennial streams (the Colorado, Green, and San Juan rivers) has been calculated to be approximately 0.24 meter (0.8 foot) per 1,000 years or less (WCC, 1983, ONWI-92, pp. 40-44, Table 4-2; 1982, ONWI-290, Vol. I, pp. 3-20 to 3-21, Table 3-10). This value is obtained from the elevations of radiometrically dated lava flows, paleomagnetically reversed deposits, and fluvial terrace remnants above present river levels. The incision rates calculated from these data, which represented 27 locations reported in the literature, range from 0.03 to 1 meter (0.1 to 3.3 feet) per 1,000 years during late Tertiary and Quaternary time (WCC, 1983, ONWI-92, Table 4-2).

These data were augmented in WCC 1982 (ONWI-290, Vol. I, Table 3-10) with 11 additional data points. Recalculation of an average incision rate, using only data having either radiometric, pedologic, or paleomagnetic age control (17 data points; WCC, 1982, ONWI-290, Vol. I, Table 3-10) results in the same rate of less than 0.24 meter (0.8 foot) per 1,000 years. The compilation of these data and data reported in the literature since 1982 are presented in Section 3.2.2.2.

The most accurate estimations of incision rates are derived from radiometrically dated Tertiary or Quaternary deposits or, secondarily, deposits dated on the basis of magnetic polarity or pedologic development. The locations along the Colorado River and its major tributaries where radiometric dates are available are listed in Table 3-2, Part A. Less precise estimates based on paleomagnetically reversed deposits and soil development along these major streams are listed separately in Table 3-2, Part B. A final category, incision rates along smaller tributary streams, is also given in Table 3-2, Part D. The derivation of incision rates estimated by these methods is described in Section 3.2.2.2.

The third source of data is modern sediment yield data from stream flow measurements and sedimentation data for reservoirs (Section 3.2.2.2), which can be used to estimate historic erosion rates over an entire drainage basin. Average annual sediment yields may be estimated by periodically sampling the sediment concentration in rivers, or by measuring the changes in reservoir volume caused by sedimentation. These data can also be compared on the basis of erodibility of stratigraphic units exposed in the drainage basin (Section 3.2.2.2).

Denudation rates for watersheds in the Colorado Plateau are shown in Table 3-3. Historic denudation rates of 0.09 to 0.9 meter (0.3 to 3.1 feet) per 1,000 years, based on the data for reservoirs in lithologic units of erodibility classes 2 through 4, fall within the same range as the erosion rates calculated from geomorphic relationships (Table 3-2).

The fourth source of data is in regard to erosion by mass movement of large bedrock blocks in the grabens area of the Needles Fault zone. The grabens are an arcuate system of linear downdropped bedrock blocks that extend for 25 kilometers (16 miles) along the east side of Cataract Canyon on the Colorado River. The grabens system averages approximately 7.2 kilometers (4.5 miles) in width, and at its widest point extends 12 kilometers (7.5 miles) east from the river. Cataract Canyon is approximately 341 meters (1,120 feet) deep below the confluence of the Colorado and Green river.

Issues of interest to the siting of a repository in Davis Canyon are (1) the mechanism by which the grabens have formed, (2) the rate at which development has occurred, and (3) whether graben development will propagate eastward to the proposed GROA. Proposed mechanisms for graben formations discussed in Section 3.2.2.2 include gravitational sliding off the western flank of the Monument Upwarp into Cataract Canyon, dissolution (discussed in Section 6.3.1.6), and tectonic processes (Section 6.3.3.4).

The estimated range for the age of the graben system (discussed in Section 3.2.2.2.3) provides a means of calculating rates at which the grabens may propagate eastward to the GROA. Given the assumption that mass movement processes, hence, graben formation did not begin until after 1.4 million years ago when Cataract Canyon formed, and they have developed over a distance of 7.2 kilometers (4.5 miles) since then, the lower bound on the rate of graben formation is 5.2 meters (17 feet) per 1,000 years. The upper limit on the rate of graben growth is provided by the assumption, based on dated sediments in a graben (Betancourt and Biggar, 1985, BMI/ONWI-570, p. 22), that graben development began 85,000 years BP and has progressed eastward over a distance of 12 kilometers (7.5 miles) from the river (Section 3.2.2.2.2.3). These parameters provide a maximum rate of graben development of 140 meters (465 feet) per 1,000 years. At its closest distance, the eastern margin of the grabens is 16.4 kilometers (10.5 miles) from the proposed geologic repository operation area in Davis Canyon. If graben development were to continue eastward at the maximum rate estimated without being influenced by the geologic structure of the Monument Upwarp, grabens might begin to form in the GROA within approximately 120,000 to 3,250,000 years.

This time span, particularly the lower bound, is considered a very conservative estimate due to the structural influence of the Monument Upwarp.

A fifth source of data is the erodibility of bedrock units (Section 3.2.2.2) that overlie the repository horizon. In the vicinity of the site, Indian Creek and its tributaries are incised into sandstone and siltstone bedrock of the Permian Cutler Formation and the Cedar Mesa Sandstone (erodibility class 3 through 5) (Table 3-1). The top of the Elephant Canyon Formation informally referred to as the Indian Limestone in DOE studies (WCC, 1982, ONWI-290, Vol. II, p. 5-5), forms approximately 10-meter (30-foot) high waterfalls in both Indian Creek and Salt Creek, to the west. This nick point in the Indian Creek profile is, therefore, the datum to which all upstream flow is graded. Where exposed between the Colorado River and the waterfalls, the limestone becomes more sandy to the east and was not detected in the DOE GD-1 well (WCC, 1982, ONWI-290, Vol. II, Figure 5-3). Upstream of the limestone outcrop, Indian Creek widens to an open amphitheatre area, whereas the stream is confined to a steep-sided canyon downstream of the nick point.

The site is located on a tributary to Indian Creek, and is approximately 24 kilometers (15 miles) upstream from the mouth of Indian Creek on the Colorado River.

The long-term incision rate for streams that flow through the geologic repository operations area is assessed to be less than the long-term incision rate calculated for the Colorado, Green, and San Juan rivers. Due to the distance to the Colorado River, incision into the upper plateau surface in the vicinity of the site would have occurred later than when it occurred at the Colorado River. Resistant bedrock layers would create a larger impediment

to the downcutting of tributary streams than to the Colorado River because of the lower erosive power of the tributary streams. This assessment is evidenced by a comparison of the depth to which the respective streams have already eroded below a common datum. The Colorado River is entrenched 700 meters (2,300 feet) below its highest outermost canyon rim, represented by Grand View Point, Aztec Butte, and the Knoll, between the Green and Colorado rivers. These topographic features are the erosional remnants of a surface developed on the resistant Navajo and Wingate sandstones. In the vicinity of the geologic repository operations area, this surface is represented by Hatch and Harts points, Bridger Jack Mesa, and the mesa southeast of the geologic repository operations area. The Indian Creek amphitheater area and the adjacent geologic repository operations area are approximately 490 to 530 meters (1,600 to 1,750 feet) lower than this surface. These observations support the conclusion that long-term incision rates for Indian Creek tributaries have been and will be less than those calculated for the Colorado River.

As Indian Creek downcuts into its present bedrock channel, the rate of incision would be affected by the erodibility of rock units encountered in the subsurface. Formations that would be incised by Indian Creek are more resistant to erosion with depth, as lithologies change from siltstone to sandstone and finally to predominantly limestone of the Honaker Trail Formation (WCC, 1982, ONWI-290, Vol. I, Table 3-2; Vol. II, Figure 5-3). Erodibility would subsequently increase at the top of the less resistant Paradox Formation, which is at a depth of approximately 825 meters (2,700 feet) in the site area.

The long-term rate of incision that has been calculated for the major rivers in the Paradox Basin represents an average rate for incision through the rock units of varying erodibilities. The Colorado River, for example, has eroded down to the top of the Paradox Formation southwest of the site (Huntoon et al., 1982). Therefore, the long-term rate of incision is assessed to be a reasonable estimate of the average rate at which stream incision will probably occur in the site during the lifetime of the repository.

The sixth source of data addresses the rate of scarp retreat. Sudden failure of blocks from cliff walls and bedrock ledges appears to be the dominant mechanism of scarp retreat and therefore, valley widening in southeastern Utah (Section 3.2.2.2.2).

Estimated rates of scarp retreat for the repository area can be examined in terms of the relaive erodibilility of the local stratigraphic units, which is discussed in Section 3.2.2.2.2. Calculated rates (Table 3-4) based on long-term geomorphic relationships (WCC, 1980, Table 4-5) range from 0.24 to 0.5 meter (0.8 to 1.8 feet) per 1,000 years in formations of erodibility classes 2 through 5, and from 7 to approximately 23 meters (23 to 74 feet) per 1,000 years for the Book Cliffs, which are developed in the Mancos Shale (erodibility class 7). In the areas being considered for repository siting, strata of erodibility class 7 have already been removed and incision that occurs during the lifetime of the repository will be occuring in rock units of erodibility classes 2 through 5 (Section 3.2.2.2.2). Therefore, a scarp retreat rate pertinent to repository siting is approximately 0.24 to 0.5 meter (0.8 to 1.8 feet) per 1,000 years.

Assumptions and Data Uncertainties. Several assumptions are included in the assessment of future rates of erosion. The first assumption is that tectonic uplift of the Colorado Plateau, which is a significant factor in determining the rate of the river incision, shall continue to occur during the lifetime of the repository, and at the same rate that it has occurred during late Cenozoic and Quaternary time (Section 3.2.5.4).

The second assumption relates to short-term perturbations in incision rates. The long-term incision rates, some of which were calculated on the basis of a time span of several million years (Table 3-2), mask chronologically short-term perturbations in the rate at which this process is occurring, as evidenced by the data available at Glenwood Springs and the Grand Canyon. Short-term variations in the downcutting rate probably occur because of changes in bedrock lithology, climatic changes, regional tectonic processes, and changes in the rate of plateau uplift. Time periods when the incision rate has been greater than the calculated long-term values have been counterbalanced by times when the opposite has occurred.

The third assumption considers the incision rate of the Colorado River. In calculating rates for river incision on the Colorado Plateau, Quaternary or late Pliocene deposits were identified along the Colorado River from Glenwood Springs, Colorado to the Grand Canyon, Arizona. Amounts of incision since deposition of these and other deposits along other rivers were used to derive long-term incision rates for the site. Radiometric dates on lava flows are available in only a few places along the Colorado River Canyon. However, the available data do indicate that the innermost part of the Grand Canyon may be older than the inner canyon at Glenwood Springs. During the last 1.2 million years, the river has downcut only 15 meters (50 feet) at Lava Falls in the Grand Canyon (McKee et al., 1968, p. 133). At Glenwood Springs, a 1.5 million-year-old lava flow is 305 meters (1,000 feet) above the present canyon bottom (Larson et al., 1975). These variable rates during the same time period may represent a stream that is near equilibrium in the Grand Canyon, and a stream that is downcutting to reach equilibrium farther upstream in Colorado. Therefore, the calculated long-term incision rate is an averaged value in terms of both short chronologic perturbations and the variable geomorphic processes operating along the length of a fluvial system.

The fourth assumption is that the incision rates calculated from the Glenwood Springs, Colorado data reported by Larson et al. (1975) have not been affected by salt flowage and tectonics in the Pennsylvanian evaporite deposits that extend eastward from the Glenwood Springs area (Tweto, 1979). This consideration was not addressed by the authors in their studies.

The fifth assumption is in regard to accuracy of erosion rates derived from modern sediment yield data. For greatest accuracy, sediment concentration data should include the suspended, dissolved, and bed components of total stream load; however, suspended load is usually the only component measured. Techniques used to measure suspended loads commonly underestimate true sediment concentrations (Brown, 1945). The bed load is sometimes estimated as a percentage of the total load, and the dissolved load (the smallest component in arid regions containing mostly clastic rocks) is sometimes estimated or measured but is commonly ignored.

Erosion rates based on sediment yield data are most accurate if the sediment concentration records span several decades because short-term climatic fluctuations can significantly affect sediment yields (Brown, 1945). Erosion rates based on reservoir sedimentation data are reasonably accurate if the period of records is for at least 10 years. In one study, 80 percent of sediment yield values calculated from reservoir sedimentation were judged to be within 30 percent of the correct values, and the remaining 20 percent were thought to be within 75 percent of the correct values (Brown, 1945). This is considerably more accurate than sediment concentration data.

Historical erosion rates can be calculated by estimating the average annual sediment yield (commonly stated in tons per square mile) from a drainage basin. An average bedrock density (usually 2.64 grams [0.09 ounce] per cubic centimeter) was used to convert the mass of removed sediment to an average rate of lowering of the ground surface (commonly stated in inches or feet per thousand years).

The sixth set of assumptions was used to calculate the rate of graben growth eastward to the GROA. In deriving these calculations, it was assumed that the Monument Upwarp would not influence the rate of graben development, and that graben formation began between 85,000 and 1,400,000 years BP. The grabens are concentrated on the western flank of the Monument Upwarp (Figures 3-6 and 3-28), which dips gently to the west. At the Davis Canyon site, which is approximately 14.5 kilometers (9 miles) east of the crest of the upwarp (Kitcho et al., 1984, Figure 3-1), the strata dip 1.6 degrees to the northeast (Section 3.2.5). If the grabens are a manifestation of mass movement processes resulting from the erosion of Cataract Canyon, the grabens should not propogate eastward over the crest of the upwarp. Therefore, they would not reach the site, where the strata dip in the opposite direction.

In using the date derived for a geologic sample collected from graben fill to calculate the minimum age of the grabens, it was assumed that the 65,370-year date accurately reflects the time when the graben formed. The structure would actually be older, having formed prior

to the time when sediment accumulated in it. Additionally, the depth of the fill is not known; the sample was collected from the ground surface, and may represent only the youngest, surficial layer of several tens of meters of sediment accumulated through time in the graben. Therefore, the date reflects only the minimum age of the graben.

It is also assumed that the 65,370-year date is an accurate reflection of the age of the deposit. The date was derived using thermoluminescence (TL) analysis, a relativley new dating technique in the scientific community. However, the date is supported by a second TL date of 61,540, which was derived from sediments approximately 1 meter (3.3 feet) stratigraphically above the first dated sample. Therefore, the dates have been interpreted as acceptable data.

The seventh assumption addresses the application of subsurface data. In the derivation of depth to the proposed repository horizons at the geologic repository operations area, it was assumed that very little deformation, caused by tectonism, salt flow, or salt dissolution, has affected the relatively flat-lying salt beds (WCC, 1982, ONWI-290, Vol. II, pp. 5-10). Therefore, it is assumed that the stratigraphic interval of interest can be projected into the site area as a continuous slab. These assumptions regarding the uncomplicated, predictable stratigraphy of the saline facies in the site are based on studies by others of the Paradox Basin and the interpretation of well data (Section 3.2.3.). Because of the inferred regularity of the saline sequence, actual depths to the top of the proposed repository horizon are expected to be within 30 meters (100 feet) of the estimates given above. It is judged to be highly unlikely that the error in the estimate would be as great as 150 meters (500 feet).

Analysis. The evaluation used to show compliance with the requirements of the Technical Guideline follows the approach presented above. Using the long-term rate of incision, of 0.24 meter (0.8 foot) per 1,000 years, the maximum depth to which the Indian Creek tributary in the site is expected to incise is 2.4 meters (8 feet) in 10,000 years and 240 meters (800 feet) in one million years. Using a higher rate (a maximum of 0.4 meter [1.2 foot] per 1,000 years) calculated for glacial-stage fluvial deposits along Pack Creek, near Moab, the depth of incision would be 4 meters (12 feet) and 400 meters (1,200 feet), respectively, for time periods of 10,000 years and one million years. These projected depths of incision are considered to be conservative estimates.

All of the depths of erosion calculated above do not intercept the top of the Paradox Formation, which is expected to be at a depth of 825 meters (2,700 feet) in the geologic repository operations area.

6.3.1.5.2 Analysis of Favorable Conditions.

(1) Site conditions that permit the emplacement of waste at a depth of at least 300 meters below the directly overlying ground surface.

Evaluation. Salt Cycle 6 is estimated to occur at a depth of approximately 885 meters (2,900 feet) (Section 3.2.3).

The evidence indicates that the favorable condition is present.

(2) A geologic setting where the nature and rates of the erosional processes that have been operating during the Quaternary Period are predicted to have less than one chance in 10,000 over the next 10,000 years of leading to releases of radionuclides to the accessible environment.

Evaluation. The following evaluation considers whether the nature and rates of erosional processes operating in the geologic setting during the last 2 million years would, if continued into the future, have an unacceptable probability of creating pathways for radionuclides to reach the accessible environment. Based on the description of the nature and rate of the erosional processes given above, streams are predicted to erode no more than approximately 4 meters (12 feet) below the present ground surface in 10,000 years. Given that the wastes will be buried at depths exceeding 885 meters (2,900 feet), it is highly unlikely that erosion will lead to releases of radionuclides to the accessible environment in the next 10,000 years.

The evidence indicates that the favorable condition is present.

(3) Site conditions such that waste exhumation would not be expected to occur during the first one million years after repository closure.

Evaluation. Based on the conservative long-term incision rate given above, streams in the site are projected to erode no more than 240 meters (800 feet) into their present stream channels during the first one million years after repository closure. However, due to the likely occurrence of another glacial period during this time period, a potential depth of erosion has been calculated using the incision rate of 0.4 meter (1.2 feet) per 1,000 years. On this basis, a maximum depth to which incision is expected to occur during this time period is 400 meters (1,300 feet). These projected depths of incision are considered to be conservative estimates. The above discussions indicate that it is unlikely that the grabens would propagate eastward across Monument Upwarp. However, even though conservative estimates of the graben propagation rate indicates that the grabens could reach into the GROA within the next one million years, this process would not exhume the waste. The repository might be disrupted, but the waste, at elevation 675 m (2,220 feet), would still be buried below the expected river level in Cataract Canyon. Applying the conservative incision rate of 0.24 meter (0.8 feet) per 1,000 years, the Colorado River level in Cataract Canyon is projected at approximately 815 meters (2,670 feet) elevation.

The evidence indicates that the favorable condition is present.

6.3.1.5.3. Analysis of Potentially Adverse Conditions.

(1) A geologic setting that shows evidence of extreme erosion during the Quaternary Period.

Evaluation. During the Quaternary Period, erosion in the candidate area has been almost continuous, with intervals during which fluvial terraces (representing intervals of deposition) were formed along streams and major rivers. However, the conservative, long-term rate of incision, less than 0.24 to 0.4 meter (0.8 to 1.2 foot) per 1,000 years, is not judged to be an extreme rate.

The evidence indicates that the potentially adverse condition is not present.

(2) A geologic setting where the nature and rates of geomorphic processes that have been operating during the Quaternary Period could, during the first 10,000 years after closure, adversely affect the ability of the geologic repository to isolate the waste.

Evaluation. Projection of the nature and rates of geomorphic processes that will affect the site during the first 10,000 years after closure is based on geologic evidence of the influence of these processes on the area during the last 10,000 years and during Wisconsinan time (the last 125,000 years). No significant bedrock incision has occurred in the site during the last 7,760 $\pm$ 155 years (Section 3.2.2.2.1), and probably not since the end of late Wisconsinan climatic conditions approximately 10,000 or 11,000 years BP. Data extrapolated from soil development on stream terraces attributed to Wisconsinan climatic changes indicate that the average rate of bedrock incision during this period of fluctuating climatic conditions was comparable to the long-term incision rate (Table 3-2; WCC, 1982, ONWI-290, Vol. II, pp. 4-13). Other geomorphic processes (mass-wasting, eolian, glacial) are not expected to affect the underground repository (WCC, 1982, ONWI-290, Vol. I, pp. 3-3 and 3-27). Based on the Quaternary geologic record, geomorphic processes should not adversely affect the ability of the repository to isolate the waste.

If graben development is due to mass movement processes, and were to continue eastward across the Monument Upwarp into the GROA, it is estimated that graben formation would not disrupt the site until a minimum of 120,000 years from the present. Therefore, eastward propagation of the graben system would not adversely affect the ability of the geologic repository to isolate the waste during the first 10,000 years after closure.

The evidence indicates that the potentially adverse condition is not present.

6.3.1.5.4 Analysis of Disqualifying Condition.

> The site shall be disqualified if site conditions do not allow all portions of the underground facility to be situated at least 200 meters below the directly overlying ground surface.

The disqualifying condition does not apply to the site because the proposed repository horizon is at a minimum depth of approximately 885 meters (2,900 feet) below the ground surface.

The evidence does not support a finding that the site is disqualified (Level 1).

6.3.1.5.5 Conclusion for the Qualifying Condition. The requirements of this guideline are that the radionuclide releases to an unrestricted area resulting from this qualifying condition are not greater than those allowable under the requirements of 10 CFR Part 60 and 40 CFR Part 191.

The data presented above show that the underground facility shall be constructed at a depth such that erosional processes acting on the ground surface would not jeopardize the integrity of the repository and thus would not lead to radionuclide release during the first 1,000,000 years of operation.

The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.3.1.6 Dissolution, Guideline 10 CFR 960.4-2-6

The objective of the Technical Guideline on dissolution is to ensure that dissolution processes will not adversely affect the waste-isolation capabilities of the site. The principal concern is that the dissolution of the host rock might create new pathways for radionuclide migration to the surrounding geohydrologic system. The sites with salt as the host rock are the most vulnerable to dissolution, and the effects of salt dissolution on waste isolation will be an important consideration in evaluating a site in salt.

This guideline includes a qualifying condition, one favorable condition, and one potentially adverse condition for analysis. It also has one disqualifying condition.

6.3.1.6.1 Statement of Qualifying Condition.

> The site shall be located such that any subsurface rock dissolution will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1. In predicting the likelihood of dissolution within the geologic setting at a site, the DOE will consider the evidence of dissolution within that setting during the Quaternary Period, including the locations and characteristics of dissolution fronts or other dissolution features, if identified.

Evaluation Process. Relevant data, such as the locations of known and possible dissolution features in the geologic setting are provided. A discussion of assumptions and uncertainties associated with the evaluation is presented, and an assessment is made of dissolution within the context of the guideline. The evaluations and findings are summarized in Table 6-10.

Relevant Data. This analysis includes several primary data sources. These include:

- The locations and characteristics of known and potential dissolution features relative to the geologic repository operations area (GROA) (WCC, 1982, ONWI-290, Vol. II; McCleary and Romie, 1985)

- Reflection seismic geophysical surveys of the candidate area (Kitcho et al., 1984)
- Gravity surveys (Kitcho et al., 1984)
- Geophysical logs of petroleum exploration holes in the candidate area (McCleary and Romie, 1985)
- Surface mapping data (WCC, 1982, ONWI-290, Vol. II)
- Core and geophysical logs of the Gibson Dome No. 1 (GD-1) borehole (WCC, 1982, ONWI-388)
- Chemical analyses of salt precipitants and ground water (WCC, 1982, ONWI-290 Vol. I; McCulley et. al., 1984; Sayala, 1985; Kunkle, 1984).

The reflection seismic and gravity survey data were acquired from petroleum exploration sources and are proprietary. Survey locations and title blocks showing recording and processing parameters for these data are compiled (Carbiener, 1985).

The known dissolution features in the candidate area are Lockhart Basin (located approximately 19 kilometers [12 miles] north of the GROA) and Beef Basin (located approximately 23 kilometers [14 miles] southwest of the GROA). The potential dissolution features in the candidate area are the Needles Fault zone, and the Shay/Bridger Jack/Salt Creek graben system. These features are 17 kilometers (10.5 miles) west and 15 kilometers (9 miles) south of the GROA, respectively.

In Lockhart Basin, well control, seismic reflection surveys, geomorphic relationships (surface mapping), and gravity surveys indicate that all or part of the salt in the Paradox Formation has been removed over an area of approximately 23 square kilometers (9 square miles). The Wingate Sandstone rims Lockhart Basin, and erosional remnants of this formation in the center of the basin occur at elevations approximately 275 meters (900 feet) lower than the rim. The area of dissolution is roughly circular and bowl shaped with no salt present in the center of the basin and a partial salt section present on its flanks. A number of breccia pipes are present in Lockhart Basin (Huntoon and Richter, 1979, pp. 45-53). These pipes of resistant, cemented, breccia project as small hills above the surrounding country rock which is often gently infolded for a few hundred feet around the pipes. The exact origin of the breccia pipes is uncertain; they are probably related to the dissolution of salt as their occurrence is confined to the area of salt dissolution.

Lockhart Basin is underlain by a system of northwest-trending faults (Kitcho et al., 1984, pp. 14-15). Well control and seismic reflection surveys confirm that some of the faults have sufficient displacement to have juxtaposed Paradox Formation salt against the Leadville Limestone. It is probable that salt dissolution is related to this structural juxtaposition. The Lockhart Fault (a northeast-trending structure mapped at the surface) appears to bound the northwestern side of the dissolution bowl and is thought to be a tensional feature related to the collapse of the basin (Section 3.2.5.1). The results of a gravity survey of the area indicate that a gravity high is present over Lockhart Basin (Kitcho et al., 1984, p. 19). This anomaly is interpreted to reflect the absence of low density salt.

Beef Basin is not as well defined a feature as Lockhart Basin. The original thickness of the Paradox Formation in the area of Beef Basin was approximately 300 meters (1,000 feet), compared to approximately 750 meters (2,500 feet) in Lockhart Basin (McCleary and Romie, 1985; Figure A-9) and the percentage of salt in the formation, based on regional depositional trends, was probably less (Elston et al., 1962; Figure 1). This is interpreted to explain the observation that the geologic and geomorphic features characteristic of dissolution at depth which are dramatically displayed in Lockhart Basin are not as well developed in Beef Basin. The Cedar Mesa Sandstone is the only unit cropping out in the vicinity of Beef Basin and, without other stratigraphic units exposed, accurate estimates of the amount of downwarping are not possible. No breccia pipes have been noted in Beef Basin. Geophysical logs of petroleum

exploration wells in Beef Basin indicate that salt dissolution has occurred but well control is so sparse that it is not helpful in delineating the boundaries of the basin.

The seismic reflection information from Beef Basin were not interpretable; therefore, the subsurface structural configuration of the basin is not well known at this time. Beef Basin is also outside the limit of the gravity survey conducted for this program so its gravity signature is not known at this time.

The Needles Fault zone is an area of potential dissolution. Huntoon (1982) discusses several theories of origin for the Needles Fault zone and concludes that the most likely mechanism is gravity-driven, down-dip gliding of a brittle plate over the Paradox Formation salt. Regardless of the exact mode of formation, the Needles Fault zone presently contains many open fractures that can provide pathways for meteoric water or ground water to reach the salt of the Paradox Formation and cause dissolution. Saline springs with a salt concentration of approximately 20,000 milligrams per liter (less than seawater) are present in Cataract Canyon of the Colorado River adjacent to the Needles Fault zone. This is suggestive of dissolution within the salt (WCC, 1982, ONWI-290, Vol. II, pp. 9-8 and 9-9). At the present time, no borehole or reflection seismic data are available from within the Needles Fault zone and the exact age of formation of the fault zone is not known. Therefore, the possible amount and rate of dissolution that may be occurring within the Needles Fault zone is not known.

The Shay/Bridger Jack/Salt Creek Graben system is another area of potential salt dissolution. The faults bounding the grabens as mapped at the surface (Figure 3-25, Section 3.2.5.1) have displacements ranging up to 98 meters (320 feet). Interpretation of seismic reflection data indicates that the Mississippian (Leadville Limestone) surface is offset 30 meters (100 feet) (Kitcho et al., 1984, p. 10). The seismic reflection data are not clear on the continuity of the surface faults with the faults cutting the Mississippian strata (Kitcho et al., 1984, p. 11). For the purpose of this discussion, these faults are considered as features that may provide a pathway for ground water that could result in dissolution. However, it should be noted that the Shay/Bridger Jack/Salt Creek Graben system has a sharp surface expression unaccompanied by downwarping, infolding, or breccia pipes, and that seismic reflection data show no indication of dissolution along these structures. The station spacing of the gravity survey limited the minimum resolvable anomaly width to 3.2 kilometers (2 miles) (Kitcho et al., 1984, p. 6); therefore narrow features such as Shay Graben are not observed in the data. There is one borehole located between the Shay and Bridger Jack Grabens, but no geophysical logs are available for the salt section, so no evaluation of dissolution was possible at that location.

Seismic reflection data in Davis Canyon indicate that all of the Paleozoic reflectors are undisturbed and dip gently to the northeast (Kitcho et al., 1984, p. 16). There is a small-displacement fault (30 meters [100 feet]) in Davis Canyon but it appears to be confined to the Precambrian crystalline basement. The closest fault to the Davis Canyon site that cuts the Leadville Limestone is fault R, a northwest-trending fault 1.6 kilometers (1 mile) north of the GROA (Figure 3-27), with an interpreted maximum displacement of 80 meters (265 feet) (Kitcho et al., 1984, Figure 5-3). Isopach maps (McCleary and Romie, 1985, Figures A-5, A-7) indicate that the combined thickness of the Molas and Pinkerton Trail formations is 110 meters (365 feet) at fault R. Since these two formations separate the Leadville Limestone from the Paradox Formation, it is interpreted that the Leadville Limestone and the Paradox Formation are not juxtaposed by fault R. Such juxtaposition is thought to be related to dissolution in Lockhart Basin.

The gravity survey indicated dissolution in Lockhart Basin, as discussed earlier. Additionally, gravity data show indications of dissolution along the Trough Springs Fault approximately 6.4 kilometers (4 miles) northeast of the basin. In the vicinity of Davis Canyon, no gravity anomalies were observed that would indicate significant subsurface geologic structures (Kitcho et al., 1984, p. 20).

Another source of data relevant to identifying dissolution within the site area is the evaluation of borehole geophysical logs. Five boreholes (Figure 3-12, boreholes 26, 27, 29, 33 and 35), including continuously cored GD-1, penetrate the full thickness of the Paradox

Formation or deeper strata near the site. No features characteristic of post-Pennsylvanian salt dissolution (e.g., breccia zones, concentrations of insoluble residues) were observed in the core from GD-1. Geophysical logs of the four other boreholes that penetrate the Paradox Formation near the site were compared to the GD-1 logs; no anomalous geophysical signatures indicative of dissolution were observed. In Lockhart Basin, where dissolution did occur, it is recognized on geophysical logs by erratic, inconsistent log signatures (McCleary and Romie, 1985, p. 60).

Field mapping is yet another data source within the site and its vicinity. Surface geology in all or part of the site has been mapped by Detterman (1955), Huntoon et al. (1982), Lewis and Campbell (1965), and WCC (1982, ONWI-290, Vol. II). None of these investigations detected features within the site vicinity that are known to be indicative of dissolution at depth such as faulting, breccia pipes, structural collapse, or infolding of surface strata.

A last data source is chemical analyses of ground water in boreholes in the region and ground-water precipitates at springs in the candidate area. The high salinity of Leadville Limestone water samples at the GD-1 borehole indicates salt dissolution (McCulley et al., 1984, Table 3-1). However, no isotopic evidence was found to indicate that circulating ground waters are modern meteoric waters. Regional data on total dissolved solids (TDS) (WCC, 1982, ONWI-290, Volume 1, Figure 9-17) indicate that TDS generally increases to the northeast of the site, indicating that the source of the salinity observed in the GD-1 borehole is in the fold and fault belt of the basin or in known dissolution areas (e.g., Lockhart Basin). Isotopic evidence (McCulley et al., 1984) suggests that the Honaker Trail Formation water, which overlies the Paradox Formation, is an admixture of evaporated seawater and ancient meteoric water. This argues against geologically recent dissolution and suggests the source of the Honaker Trail water is ancient connate or diagenetic water.

Analyses of salt crust at springs in the candidate area (Sayala, 1985; Kunkle, 1984) suggest that the salts are leached from finely disseminated salt in the Cedar Mesa Sandstone by local, shallow ground water. No deep ground water source is indicated for the seeps or the salts precipitated (Section 3.3.2), as would be the case if they were related to dissolution.

Assumptions and Data Uncertainty. Within the candidate area, evidence for identified dissolution features consists of sagging or down-warped surface strata, faulting, breccia pipes, anomalous seismic reflection patterns, and the absence or partial absence of salt as indicated on borehole geophysical logs. A major assumption of this discussion is that if these characteristics are absent in an area, as they are in the site, no significant salt dissolution has occurred. The major data limitations are the sparse distribution within the site vicinity of wells that penetrate the Paradox Formation, and limited seismic reflection coverage. The only element providing uniform coverage of the site is the surface mapping data. It is estimated that the limit of detection for dissolution features from surface mapping is approximately 31 meters (100 feet) of vertical dissolution over an area of 2.6 square kilometers (1 square mile) which is approximately ½ degree of dip. Features smaller than this, if they exist, probably would not be detected. Data on dissolution-related Quaternary deformation is limited because of the scarcity of Quaternary deposits at critical locations in the geologic setting and at the site.

Analysis. The evaluation of dissolution in the site geologic setting, during the Quaternary Period, is addressed in the following evaluations of conditions. There are no indications of Quaternary-age dissolution at the site. The locations of known and suspected dissolution features are provided in the preceding discussion and in Section 3.2.5.6. None of these features are expected to affect the isolation capabilities of the site in the next 10,000 years, as discussed in Section 6.3.1.6.4.

6.3.1.6.2 Analysis of Favorable Condition.

No evidence that the host rock within the site was subject to significant dissolution during the Quaternary Period.

Evaluation. Within the limitations of the data discussed above there is no evidence of Quaternary or earlier dissolution within the site.

The evidence indicates that the favorable condition is present.

6.3.1.6.3 Analysis of Potentially Adverse Condition.

> Evidence of significant dissolution within the geologic setting--such as breccia pipes, dissolution cavities, significant volumetric reduction of the host rock or surrounding strata, or any structural collapse--such that a hydraulic interconnection leading to a loss of waste isolation could occur.

Evaluation. Dissolution features are found in the geologic setting. The locations and characteristics of the known or potential dissolution features nearest the site are discussed in Section 6.3.1.6.1. No evidence of dissolution, such as that described in the statement of the potentially adverse condition, has been identified in the site. However, there is insufficient information to conclude that dissolution in the geologic setting could not result in a hydraulic interconnection leading to a loss of waste isolation.

The evidence indicates that the potentially adverse condition is present.

6.3.1.6.4 Analysis of Disqualifying Condition.

> The site shall be disqualified if it is likely that, during the first 10,000 years after closure, active dissolution, as predicted on the basis on the geologic record, would result in a loss of waste isolation.

Evaluation. The presently available data indicate that there is no dissolution within the site. The closest known or potential dissolution feature is the northeastern terminus of the Bridger Jack Graben, located 14.5 kilometers (9 miles) south of the proposed GROA. If it were assumed that an active dissolution front did exist at this distance from the proposed repository, and, that the structural, stratigraphic, and hydrogeologic conditions of the area are such that the dissolution front would migrate directly toward the GROA, then in order for the dissolution front to reach the repository in 10,000 years, it would have to progress at a rate of 144.78 centimeters per year (4.75 feet per year).

This hypothesized advance rate of 144.78 centimeters per year (4.75 feet per year) can be compared to measured advance rates of natural salt dissolution fronts in other areas. For example, in the Texas Panhandle where salt dissolution is suggested to be a major cause of landscape evolution, Gustavson et al. (1980, p. 36) give calculated maximum horizontal dissolution rates ranging from 0.07284 centimeters per year (0.00239 feet per year) to 98.398 centimeters per year (3.2283 feet per year). Of the rates presented for 16 different areas, 15 have maximum calculated rates of 14.5847 centimeters per year (0.47850 feet per year) or less. The minimum rates for all areas listed range from approximately 0.0055 centimeters per year (0.00018 feet per year) to approximately 64.29 centimeters per year (approximately 2.11 feet per year). Studies conducted in New Mexico for the Waste Isolation Pilot Plant (WIPP) project (Weart, 1981, p. 429) indicate that the regional shallow dissolution front is advancing at a rate less than 0.9656 centimeters per year (0.03168 feet per year) to 1.2875 centimeters per year (0.04224 feet per year). This comparison shows that, in areas of known active natural dissolution, advance rates are generally less than 10 percent of that which would be required for a dissolution front to migrate the distance assumed for this evaluation.

Solution mining at the Cane Creek Potash Mine near Moab provides a mining-induced dissolution rate within the Paradox Basin. When the mine was flooded (1971), there were 547 kilometers (340 miles) of headings in the potash bed being mined. In the solution process, water is pumped into the mine from the Colorado River, remains there for 300 to 350 days to produce brine, and is then extracted from the low point in the mine. Using this system, the walls and pillars of the entry system are expected to dissolve at rates of approximately 15.24 centimeters per year (0.5 feet per year) to 20.42 centimeters per year (0.67 feet per

year), with a maximum of 30.48 centimeters per year (1.0 feet per year) near the injection wells (Jackson, 1973, pp. 3-4).

All of the rates discussed above have been for horizontal dissolution front advance. Hite and Lohman (1973, p. 40) calculated the vertical dissolution rate over a 336 square-kilometer (130 square-mile) area comprised of the collapsed crests of the Gypsum Valley, Paradox Valley, and Sinbad Valley salt anticlines in the Paradox Basin. Vertical dissolution was calculated to be proceeding at a rate of 0.02743 centimeters per year (0.0009 feet per year).

Based on the above rates, it could be expected that if active dissolution fronts exist in the site vicinity and are advancing at even 10 percent of the hypothesized 144.78 centimeters per year (4.75 feet per year) rate, then abundant indicators would exist as in the Texas panhandle and New Mexico. Since dissolution front advance rates elsewhere are generally less than 10 percent of the rate required to migrate a dissolution front from the nearest potential source to the site in 10,000 years, and since no subsurface or topographic evidence of advancing dissolution fronts have been observed within 14.5 kilometers (9 miles) of the proposed GROA, it is judged unlikely that a dissolution front will encroach upon the GROA and cause a loss of waste isolation within the next 10,000 years.

As an additional comparison, even if the hypothetical dissolution front were to advance at a rate of 98.398 centimeters per year (3.2283 feet per year), the high maximum rate presented in Gustavson et al. (1980, p. 36), it would take a front 14,720 years to advance from the nearest potential dissolution feature to the GROA.

The evidence does not support a finding that the site is disqualified (Level 1).

6.3.1.6.5 Conclusion for the Qualifying Condition. The requirement states that subsurface rock dissolution will not be likely to lead to radionuclide releases greater than those specified by the NRC and EPA. The analysis presented above indicates that no effects of dissolution are observed in the site and that active dissolution fronts are not expected to result in a loss of waste isolation during the next 10,000 years.

The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.3.1.7 Tectonics, Guideline 10 CFR 960.4-2-7

Meeting the requirements of the postclosure guideline on tectonics will provide a high degree of confidence that tectonic processes will not adversely affect the waste-isolation capabilities of the site. Tectonic processes and events during the postclosure period could adversely affect waste containment and isolation by creating new ground-water pathways to the accessible environment, altering ground-water travel times, or physically altering the local waste environment. Although it is difficult to predict geologic processes with certainty, this guideline requires that the tectonic history of a site be carefully examined and the results of this examination be used to determine whether the likelihood for significant future tectonic activity is acceptably small. Igneous activity, uplift, subsidence, folding, and faulting are all important tectonic processes and are included in this guideline.

This guideline includes a qualifying condition, a favorable condition, and six potentially adverse conditions for analysis. It also has a disqualifying condition.

6.3.1.7.1 Statement of Qualifying Condition.

> The site shall be located in a geologic setting where future tectonic processes or events will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in 10 CFR 960.4-1. In predicting the likelihood of potentially disruptive tectonic processes or events, the DOE will consider the structural, stratigraphic, geophysical, and seismic evidence for the nature and rates of tectonic processes and events in the geologic setting during the Quaternary Period.

Evaluation Process. To determine whether the Qualifying Condition with respect to tectonics specified in 10 CFR 960.4-2-7 can be met, relevant data are summarized and evaluated. Assumptions and uncertainties are discussed and a brief analysis is provided. Evaluations are made regarding favorable and potentially adverse conditions at the site. These conditions and findings are summarized in Table 6-10. Conclusions drawn with respect to qualification of the site for further consideration as a potential repository are presented along with a rationale for these conclusions. Cross referencing is provided to other sections of the report.

Relevant Data. A comprehensive review of published geologic literature has been conducted emphasizing the geologic history of the Paradox Basin, including the entire Colorado Plateau and the surrounding regions of greater geologic activity (WCC, 1982, ONWI-290, Vol. I). These data are reviewed in Section 3.2.5 and are briefly summarized below.

The site lies within the central portion of the Colorado Plateau. The tectonic history of the region was dominated by two major episodes of faulting and folding. The early episode lasted from approximately 310 to 270 million years ago (coincident with Ancestral Rockies), and the latter one lasted from approximately 70 to 40 million years ago (Laramide Orogeny) (WCC, 1982, ONWI-290, Vol. 1). The gentle folds that characterize the candidate area were produced in the latter episode. Igneous intrusives (the Abajo and La Sal Mountains) were emplaced approximately 27 million years ago in the vicinity of the site. The closest known area of Quaternary age volcanism lies 127 kilometers (79 miles) east of the site (Figure 3-33 and Section 3.2.5.3).

The most significant late Cenozoic tectonic process has been regional uplift that resulted in the erosion of the deep canyons of the Colorado River system. This uplift has been relatively slow, i.e., probably less than 0.6 meter (2 feet) per 1,000 years for the last 700,000 years (Section 3.2.5.4).

Geologic mapping of the site vicinity has not indicated the presence of surface faults. Mapping of steep scarps along Shay Graben, south of the site, indicates that this feature may have been reactivated during the Quaternary (Section 3.2.5.1).

Geophysical studies included interpretation of a considerable amount of seismic reflection data for the area. Subsurface faults that may extend upward into the lower part of the Paradox Formation are found in the northeastern and north-central part of the site vicinity (Section 3.2.5.1).

Regional seismologic studies include a review of the historical seismicity of the Colorado Plateau and an evaluation of some of the larger events that have occurred within the Plateau, but outside the Paradox Basin. During the period of the historical seismicity record, 1850 to 1979, no earthquakes are known to have occurred within the site (Section 3.2.5.2). A local network of seismographs capable of recording very small earthquakes has been operating since mid-1979. No earthquakes have been observed within the site. The largest earthquakes observed to date in the Utah portion of the Paradox Basin have been approximately magnitude M_L 3 (Local Magnitude) (Section 3.2.5.2).

The Paradox Basin has been classified as a seismic risk zone 1, relatively low seismic risk (Algermissen, 1969, p. 26) and an area for which the expected peak horizontal ground acceleration is less than a 0.04 gravity with 10 percent probability that the value will be exceeded in 50 years (Algermissen and Perkins, 1976, p. 23). However, these conclusions are based on a historical seismicity record that has limited value by itself. Using the available seismic, geologic, and tectonic data to analyze the possible seismogenic structures within the Paradox Basin (including the Colorado Lineament), a maximum acceleration value can be estimated for the Davis Canyon site. A maximum earthquake for the entire Colorado Plateau province is estimated to be M_L 6.5 (Kirkham and Rogers, 1981, p. 17). For the EA evaluation, this M_L 6.5 earthquake is chosen as the maximum earthquake in the geologic setting. The Paradox Basin portion of the Colorado Plateau may later be found to have a smaller maximum earthquake. The analysis for the site is conservative because it is assumed that the maximum earthquake can occur on the closest significant geologic structure. Using a peak acceleration

relationship for north-central Utah (Campbell, 1982, p. 370), a peak horizontal acceleration of 0.18 gravity is estimated for an M_L 6.5 earthquake occurring on the south Shay Graben fault at a distance of 16 kilometers (10 miles), which is the closest distance to the repository operations area. Other, more distant seismogenic features such as the seismicity cluster along the Colorado River need not be analyzed at this time, because their potential effects are overshadowed by the conservative case adopted. This value may be slightly low for the Paradox Basin because attenuation may be slightly greater in north-central Utah than in the Colorado Plateau. Another relationship, not geographically specific, presented in Donovan (1982) suggests a mean peak value of approximately 0.25 gravity. These estimates indicate the general level of peak accelerations to be expected at the site. Analysis in more detail would be required to specify seismic design criteria.

Continuous temperature logging of borehole GD-1 was performed by WCC during the drilling phase and by the USGS in 1981 and 1982. The two logs collected by the USGS were almost identical, indicating that the well had reached thermal equilibrium (Sass et al., 1983). Using the USGS data for GD-1, the temperature at the repository depth (914 meters [3,000 feet]) in Davis Canyon is estimated to be 34 C (94 F). Thermal gradients determined from GD-1 showed a strong dependence on lithology. For the Elephant Canyon formation (183 to 381 meters [600 to 1,250 feet]), the temperature gradient was 23.49 C per kilometer (68.1 F per mile); the Honaker Trail formation (427 to 869 meters [1,401 to 2,851 feet]) was 21.77 C per kilometer (63.1 F per mile); the Paradox formation (945 to 1,600 meters [3,100 to 5,249 feet]) was 13.04 C per kilometer (37.8 F per mile); and the Leadville formation (1,798 to 1,922 meters [5,899 feet to 6,306 feet]) was 17.15 C per kilometer (49.7 F per mile) (Sass et al., 1983). These results are consistent with the observations by Bodell and Chapman (1982) for the north-central Colorado Plateau, where gradients from 25 drill holes varied between 10 C per kilometer (29.0 F per mile) and 37 C per kilometer (107.3 F per mile), with a mean gradient of 19 C per kilometer (55.1 F per mile). The USGS determined a mean heat-flow value of 66, plus or minus 3 milliwatts per square meter for GD-1. This is consistent with a value of 65 milliwatts per square meter determined for a drillhole north of Shafer Basin southwest of Moab, and an average value of 64 milliwatts per square meter for the area of the salt anticlines near Moab (Bodell and Chapman, 1982).

Assumptions and Data Uncertainties. Deposits younger than approximately 180 million years old are absent from the site (except discontinuous late Quaternary terrestrial deposits), making a detailed interpretation of the Quaternary geologic history of the site difficult using only the stratigraphic record. Therefore, the assumption is made that the site geologic history is similar to that observed in surrounding areas where a more complete geologic record is available. No structures were discovered in the site or area that were not consistent with the geologic history of the Paradox Basin as derived from regional studies. The geologic setting is taken to be the Paradox Basin, lying within the Colorado Plateau, as shown in Figure 3-3.

The historical seismicity record, which provides some of the basis for earthquake hazard assessment, is limited in several respects. Much of the historical record is incomplete, and some locations of past earthquakes are inaccurate because of the small and sparsely distributed population and inadequate seismographic coverage of the Paradox Basin and Colorado Plateau. The time period of the record is also short relative to geologic time. Because more complete historical records in other regions suggest seismicity can be episodic over long periods, a 130-year record may not be a good representation of the actual long-term seismic potential within the Colorado Plateau.

Microearthquake monitoring of the Paradox Basin indicates that the seismicity has varied spatially and temporally during the past 6 years. Thus, caution must be used in drawing conclusions or extrapolating from the behavior of these small magnitude events.

Analysis. All data available to date indicate that the site is located in a tectonic setting dominated by epeirogenic processes (broad-scale vertical uplift). Compared to the rest of the western United States, the central portion of the Colorado Plateau exhibits low levels of faulting, folding, heat flow, Cenozoic volcanism, and seismicity. Based on these considerations, the site is located in a favorable tectonic environment for waste isolation and containment.

6.3.1.7.2 Analysis of Favorable Condition.

The nature and rates of igneous activity and tectonic processes (such as uplift, subsidence, faulting, or folding), if any, operating within the geologic setting during the Quaternary Period would, if continued into the future, have less than one chance in 10,000 over the first 10,000 years after closure of leading to releases of radionuclides to the accessible environment.

Evaluation. The following discussion evaluates whether any of the igneous or tectonic processes operating in the central region of the Colorado Plateau (geologic setting) during the last 2 million years would, if continued into the future, have an unacceptable probability of creating a pathway for radionuclides to reach the accessible environment. Analysis of the favorable condition includes a probability analysis for the joint failure of both engineered barriers and geologic barriers. Such analysis requires site-specific data and design specific data that are not available. The tectonic data discussed below indicate very low likelihoods that disruptive tectonic events will occur, and this suggests the favorable condition will be met. Continued stability for 10,000 years is reasonable, when based on the same degree of stability exhibited over the past two million years.

Uplift. Quaternary uplift has averaged less than 0.6 meter (2 feet) per 1,000 years (Section 3.2.5.4). This rate would produce no more than 6 meters (20 feet) of uplift of the site in the next 10,000 years, which is not significant when compared to the depth of burial of the repository. Regional uplift will not affect the physical integrity of the repository, and will be too small to significantly modify ground-water flow systems during the next 10,000 years.

Faulting. No surface faults have been detected at the site. Because the only suspected active faults in the site vicinity, the Shay Graben faults, appear to be reactivated features of Laramide Age, late Cretaceous through Paleocene, (Section 3.2.5.1), and the unfaulted rocks of the site are generally more than 200 million years old, it is judged unlikely that new surface faults will develop in the next 10,000 years. Reactivation of the basement faults beneath the site is possible, but it is doubtful that displacements large enough to propagate these features through the ductile rocks of the Paradox Formation would occur in 10,000 years. Movement on basement faults below the site did not occur during the most recent period of large-scale basement deformation, which lasted about 30 million years. A fault has been postulated in Bogus Pocket north of the site, but field reconnaissance along the cliffs does not show any evidence of faulting.

Minor reactivation of faults in the vicinity of the Colorado River appears to have occurred in the area of dense microseismicity southwest of Moab. These faults appear to be favorably oriented with respect to the contemporary stress field to result in the observed seismicity. The maximum principal stress is approximately horizontal and oriented approximately east-west. However, along this zone of microearthquake activity, there is no surface expression of large scale deformation which might reflect the accumulation and release of large amounts of strain energy (significant earthquakes). A few microearthquakes have been observed in the vicinity of Shay Graben, but any correlation with the graben faults is uncertain.

Folding. The site is located on gently dipping strata, about 1 to 2 degrees dip, on the northeast flank of the Monument Upwarp. Folding resulting from large scale tectonic processes is unlikely during the next 10,000 years, because such folding has not been localized in the site area during past episodes of deformation (Section 3.2.5.4). In the site vicinity, Gibson Dome is the nearest fold having a salt core. An evaluation of this fold (Section 3.2.5.5) indicates a maximum of 30 feet (9 meters) of uplift on the fold in the next 10,000 years.

Igneous Activity. Thick lithosphere, low heat flow, crustal compression, and the absence of Quaternary volcanism in the site geologic setting make future igneous activity highly unlikely at the site. The closest Quaternary volcanism is 127 kilometers (79 miles) east of the site (Section 3.2.5.3).

The evidence indicates that the favorable condition is present.

6.3.1.7.3 Analysis of Potentially Adverse Conditions.

(1) Evidence of active folding, faulting, diapirism, uplift, subsidence, or other tectonic processes or igneous activity within the geologic setting during the Quaternary Period.

Evaluation. This condition considers active tectonic processes that may have been operating in the geologic setting during the past 2 million years. Some of the tectonic processes listed in the above condition have been operative during the Quaternary Period in the geologic setting, the Paradox Basin. The significance and rate of these processes are discussed in Section 6.3.1.7.2.

Folding. Folding, as a result of large scale tectonic processes is not known to have occurred in the geologic setting during the last 40 million years (WCC, 1982, ONWI-290, Volume I). In the salt anticlines region northeast of the site, synclines developed adjacent to the diapiric salt anticlines during the late Cenozoic as a result of lateral flow of salt. Salt dissolution and collapse along the crest of the anticlines also occurred during the Cenozoic. These folds do not occur within the site (Section 3.2.5.4). The status of folds nearest the site (Indian Creek Syncline and Gibson Dome) during the Quaternary is uncertain.

Faulting. Quaternary faulting in the geologic setting has been primarily attributed to gravitational sliding, salt flow, and salt dissolution (Section 3.2.5.1). Faulting unrelated to these processes is suspected at Shay Graben, but is not proven. This fault is interpreted to be a reactivated feature of probable Laramide age. The Graben does not trend toward the site. If Shay Graben is active, however, it could be the source of an earthquake (maximum magnitude about M_L 6.5) larger than any historically observed in the site vicinity.

Diapirism. Minor late Cenozoic salt diapirism possibly occurred in several locations within the salt anticlines region northeast of the site. Small diapirs are also located along the Colorado River over the crest of the Meander anticline (Section 3.2.5.5). No diapiric activity is recognized within or near the site since the salt was deposited (Sections 3.2.5.5 and 3.2.3), and the site is free of conditions judged to have caused salt flow elsewhere in the basin. However, some degree of salt flow has occurred within the evaporite units near the site, as indicated by salt thickening in the axis of Gibson Dome (Section 3.2.5.5) and the distortion (undulatory character) of anhydrite bands within the salt cycles (Section 3.2.3.3). Whether salt flow continued to occur during the Quaternary is uncertain. The small amount of relief (60 meters [200 feet]) on the upper surface of the salt at Gibson Dome fold is judged not sufficient to cause significant salt flow.

Uplift. The average rate of uplift for the Paradox Basin during the late Pleistocene was no greater than 0.6 meter (2 feet) per 1,000 years, and probably was close to 0.1 meter (0.3 feet) per 1,000 years. Approximately 600 meters (2,000 feet) of uplift has occurred in the site region over the last 2 million years (Section 3.2.5.4).

Igneous Activity. No known igneous activity has occurred within the geologic setting (Paradox Basin) in the last 2 to 3 million years. The closest known area of Quaternary volcanism is located 127 kilometers (79 miles) east of the site (Figure 3-33, Section 3.2.5.3).

The evidence indicates that the potentially adverse condition is present.

(2) Historical earthquakes within the geologic setting of such magnitude and intensity that, if they recurred, could affect waste containment or isolation.

Evaluation. Based on the historical seismicity record and current microearthquake monitoring, the largest earthquakes (maximum about M_L 4) that might occur within the Paradox Basin would not adversely impact waste containment or isolation. A study of earthquake damage to

underground structures evaluated 107 cases in eight countries and determined that significant damage occurred only at surface accelerations greater than 0.5 gravity. Only minor damage was observed in some cases at surface accelerations of 0.2 to 0.5 gravity (McClure, 1981, pp. 79-80). Accelerations from a magnitude 4 earthquake in basement rocks near the site (2 kilometers deep) are predicted to be less than 0.2 gravity using equations by Campbell (1982, p. 370).

The evidence indicates that the potentially adverse condition is not present.

> (3) Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or the magnitude of earthquakes within the geologic setting may increase.

Evaluation. Based on the existing seismicity record and current understanding of tectonic character of the Paradox Basin, correlations of earthquakes with tectonic processes or specific faults in the geologic setting are not well defined. Hence for the purposes of this evaluation the presence or absence of young (Quaternary Age) faulting within the geologic setting is used to assess whether or not the frequency of occurrence or magnitude of earthquakes may increase relative to the baseline provided by the historical seismicity record. In general, the observed seismicity in the geologic setting appears to be consistent with the setting's structural and tectonic character. However, there is a possibility that the south Shay Graben fault may be determined to be an active fault and therefore capable of producing an earthquake larger than any historically observed in this geologic setting. The predicted maximum magnitude is approximately M_L 6.5. It remains to be established whether the Shay Graben faults are tectonically active (i.e., not active because of salt dissolution) and seismogenic.

The evidence indicates that the potentially adverse condition is present.

> (4) More-frequent occurrences of earthquakes or earthquakes of higher magnitude than are representative of the region in which the geologic setting is located.

Evaluation. This condition asks whether the geologic setting exhibits more frequent or higher magnitude seismic events than the region in which it is situated. The frequency and magnitude of seismic events within the geologic setting (Paradox Basin) is comparable to or less than that of the central portion of the Colorado Plateau (Wong, 1984, ONWI-492, p. 2-27). The frequency and magnitude of earthquakes in the Colorado Plateau is much less than in surrounding regions (i.e., the Basin and Range, and Rio Grande Rift regions).

The evidence indicates that the potentially adverse condition is not present.

> (5) Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such magnitudes that they could create large-scale surface-water impoundments that could change the regional ground-water flow system.

Evaluation. Based on the geologic record, natural impoundments of the scale necessary to effect large changes in the regional ground-water flow system are not known to have occurred within the geologic setting. Neither volcanic activity nor subsidence has been recognized in the geologic setting (Section 3.2.5). Conceivably, catastrophic failure of the Needles Fault zone could dam the Colorado River in Cataract Canyon. Such an event is unprecedented in the history of the Colorado River and would require profound changes from the present tectonic and climatic regime. If such an event were to occur, it would have its primary effect on the upper hydrostratigraphic unit. The initial effect would be to create bank storage within this unit upstream from the dam, and slow the flow rate. After breaching the dam, the flow path to the river could be shortened by the width of the material removed by the catastrophic slide (perhaps by several kilometers). This does not appear to be a significant factor because the closest approach of the Needles Fault zone to the site is 18 kilometers (11 miles).

The evidence indicates that the potentially adverse condition is not present.

> (6) Potential for tectonic deformations--such as uplift, subsidence, folding, or faulting--that could adversely affect the regional ground-water flow system.

Evaluation. This condition considers whether tectonic processes might act to produce shorter ground-water flow paths or faster ground-water flow rates to the accessible environment. The major tectonic process now occurring in the Colorado Plateau is slow uplift. This uplift has been relatively uniform for such a large region. Because the rate of uplift is relatively slow, it is unlikely to create measurable changes in the regional ground-water flow system through warping or differential uplift over the next 10,000 years. Similarly, the relatively uniform uplift is unlikely to result in the formation of new structures (faults and folds) that would adversely affect the ground-water flow system. Reactivation of surface or subsurface faults is a remote possibility that could create new pathways between the Paradox Formation and the ground surface or the Leadville Limestone. However, fault reactivation resulting in the alteration of the hydrologic regime does not appear to have occurred in the recent geologic past.

The evidence indicates that the potentially adverse condition is not present.

6.3.1.7.4 Analysis of Disqualifying Condition.

> A site shall be disqualified if, based on the geologic record during the Quaternary Period, the nature and rates of fault movement or other ground motion are expected to be such that a loss of waste isolation is likely to occur.

Evaluation. Shay Graben and the Needles Fault zone are two structures that are known or suspected to have been active during the Quaternary Period and need to be evaluated with respect to this condition.

Faulting, as a result of tectonic activity, is suspected at Shay Graben, but is not proven. This fault is interpreted to be a reactivated feature of probable Laramide Age. The fault does not trend toward the site (see Figure 3-27). However, if the fault is found to be tectonically active, it could be the source of earthquakes (maximum magnitude about M_L 6.5) to be taken into consideration during design of repository surface facilities. However, earthquakes or faulting on this zone, which is 16 kilometers (10 miles) south of the site, are not anticipated to affect the ability of the repository to isolate waste after closure because earthquake effects are not significantly perpetuated deep underground and, as noted above, the fault does not trend toward the site and, therefore, would not intersect the repository.

The other structural feature known to be active in the candidate area is the Needles Fault zone (Lewis and Campbell, 1965, p. 831). This zone (Section 3.2.5.1) is probably a large gravitational slide (Huntoon, 1979, p. 46; Huntoon et al., 1982, p. 941; Stromquist, 1976, p. 1). As a gravitational feature, the fault zone is not expected to be a source of strong earthquakes or ground motion that could affect the site.

The evidence does not support a finding that the site is disqualified (Level 1).

6.3.1.7.5 Conclusion for the Qualifying Condition. The requirements of the qualifying condition of this guideline 10 CFR 960.4-2-7 are that future tectonic processes or events will not change conditions in the repository or regional ground-water flow system such that radionuclide releases to the accessible environment will be greater than those specified in 10 CFR 960.4-1.

Excellent bedrock exposures and relatively uncomplicated structural geology ensure a high degree of confidence that potentially hazardous features have not escaped detection. The known geology and the evident long-term geologic stability of the site indicate that foreseeable tectonic events will not be disruptive and thus will not produce effects that compromise the integrity of the repository below limits specified in 10 CFR 960.4-1.

The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.3.1.8 Human Interference and Natural Resources, Guideline 10 CFR 960.4-2-8-1

Site suitability relative to natural resources is manifested in two major concerns: (1) the repository operations may restrict access to important mineral deposits, and (2) the presence of significant mineral resources at or near the site might attract future human activities which could compromise repository isolation. The first concern is discussed under the environmental (Section 6.2.1.6) and socioeconomic (Section 6.2.1.7) guidelines. The natural resources guideline deals with the latter concern. The aim of this guideline is to favor location of a repository away from natural resources which might induce inadvertent human interference.

This guideline includes a qualifying condition, two favorable conditions, and five potentially adverse conditions for analysis. It also has two disqualifying conditions.

6.3.1.8.1 Statement of Qualifying Condition.

> This site shall be located such that--considering permanent markers and records and reasonable projections of value, scarcity, and technology--the natural resources, including ground water suitable for crop irrigation or human consumption without treatment, present at or near the site, will not be likely to give rise to interference activities that would lead to radionuclide releases greater than those allowable under the requirements specified in 10 CFR 960.4-1.

Evaluation Process. This section describes and assesses the natural resources of the site and its vicinity in terms of relevant data, assumptions, data uncertainties, and analysis related to the qualifying conditions stated above. This assessment, together with performance assessment analyses presented in Section 6.4, provides information necessary to address and evaluate site compliance with the DOE siting guidelines. The evaluations and findings are summarized in Table 6-10.

Relevant Data. Known natural resources at or near the site consist of (1) surface and near-surface deposits of uranium and vanadium; (2) subsurface deposits of potash; (3) minor surface deposits and occurrences of iron oxide, sand and gravel, and dimension stone; (4) undiscovered speculative subsurface oil and gas resources; (5) small quantities of potable ground water found in shallow wells and springs; and (6) subsurface deposits of halite. Resource production has consisted of uranium and vanadium, a minor amount of sand and gravel, and occasional use of potable water.

Known production of uranium and vanadium resources from one to four localities within the site vicinity has been described as "small" and potential resources remaining have been estimated to be "nil" (Figure 3-37, Table 3-12) (USGS, 1982). Known deposits in and near the site are restricted to the Chinle and Cutler Formations. The Chinle Formation bottom contact is located stratigraphically 914 to 1,003 meters (3,000 to 3,290 feet) above the proposed Salt Cycle 6 repository layer. The Cutler Formation contains some uranium deposits north of the site vicinity; the bottom of this formation is located stratigraphically 724 meters (2,375 feet) above the proposed Salt Cycle 6 repository layer. The maximum reported depth of any mine within the site is 11 meters (35 feet). The depth of the deepest known mine within the site vicinity is 24 meters (80 feet). Compared with areas of similar size and geology within the candidate area, the site contains a relatively small number of productive localities (Figure 3-37). Compared with similar areas elsewhere in southeastern Utah, known production from the site is very low (Section 3.2.8.2.1).

Potash mineralization, located within many of the 29 evaporite cycles of the Paradox Formation (Hite, 1960, p. 86, Figure 2), occurs primarily north and northeast of the geologic repository operations area. The estimated southern boundary of this mineralization (Hite, 1982, p. 3) traverses the site vicinity northeast of the geologic repository operations area

(Section 3.2.8.2.2, Figure 3-38). Combining potash analysis of core in borehole GD-1 with previous studies, Hite (1982, p. 3) defined an area of potentially economic potash deposits in Salt Cycle 18. Although the western limit of the deposits is poorly defined, Hite (1982, p. 7) stated, "It is likely that [the deposits] do not underlie Davis and Lavender canyons." Isopach maps of commercial-grade potash zones in Cycles 13 and 18 (Section 3.2.8.2.2) show that each potash zone is too thin (less than 3 meters [10 feet]) at the proposed Davis Canyon site to be of any economic interest now or in the foreseeable future. Zones of sylvite that are less than 3 meters (10 feet) thick in Davis Canyon, thicken to more than 12.2 meters (40 feet) in an area to the north. The GD-1 borehole showed the Cycle 13 potash zone to have a thickness of only 1.9 meters (6.2 feet), and an average grade of 16.5 percent potassium oxide equivalent. The Cycle 18 potash zone was 2.5 meters (8.2 feet), thick with an average grade of 22.1 percent potassium oxide at a depth of 1,350 to 1,352 meters (4,428.6 to 4,436.8 feet) (Hite, 1982, p. 7).

One small occurrence of iron oxide exists in the north-central part of the site vicinity (Figure 3-37; locality 64); one deposit of sand and gravel showing evidence of minor development occurs east of Utah 211, approximately 4 kilometers (2.4 miles) northeast of the geologic repository operations area. Formations that have produced dimension stone outside the candidate area (Chinle and Moenkopi) occur within the site; however, no recognized dimension stone localities occur within the candidate area or site.

Speculative hydrocarbon resources are considered for the site vicinity because the subsurface formations have been productive elsewhere in the Paradox Basin. The Paradox Formation and Leadville Limestone are the principal targets of hydrocarbon exploration in the Paradox Basin. Three types of oil and gas traps provide commercial accumulations within these targets (Section 3.2.8.1). These structural and stratigraphic trap-forming conditions have not been identified within the site or its vicinity, based on available borehole and geophysical data. The site vicinity and candidate area are located north and west of the principal producing fields in the Paradox Basin. No production, no significant oil and gas shows in drill-stem tests, and no untested structures are known to exist within the site vicinity. Cumulative recorded production is also relatively low for the candidate area with 70,000 barrels of oil and 115,000 thousand cubic feet (MCF) of gas produced to May, 1983 (Utah State Division of Oil, Gas, and Mining). In contrast, for the Paradox Basin, cumulative recorded production shows more than 476 million barrels of oil and more than 819 million MCF gas to December, 1980 (Clem and Brown, 1984). Thus, the candidate area, although comprising approximately 11 percent of the total surface area of the Paradox Basin, contains only 0.015 percent of the total basin oil production.

Ground-water use in the site vicinity and candidate area is minimal. Wells are used principally for stock watering, domestic needs of isolated homes, and Canyonlands National Park (Table 3-24 and Figure 3-54). These wells and more distant shallow wells west of the site yield small quantities of ground water from the Glen Canyon Group and Cedar Mesa/Cutler strata (Section 3.3.3.1); they are less than 122 meters (400 feet) deep. Deep ground-water resources are limited and are usually of a brackish to highly saline quality (Section 3.3.3.2).

The Nuclear Regulatory Commission (NRC) has established requirements for permanent site markers at a repository, and for wide dissemination of records about the repository and its contents (10 CFR Part 60). In its definition of unanticipated processes and events, the NRC indicates that postclosure human interference at the site is not a credible scenario so long as permanent markers exist and knowledge of a repository has been maintained. The Environmental Protection Agency (EPA) believes that markers, records, and other passive institutional controls should be effective in deterring systematic or persistent exploitation of a repository site, and that they can substantially reduce the likelihood of inadvertent intrusion as long as they endure and are understood (40 CFR Part 191). Further, the EPA states that the agencies responsible for repository siting and development should assume that a future intruder's own exploratory procedures are adequate for the intruder to soon detect, or be warned of, the incompatibility of the area with their activities. The DOE has conducted feasibility studies of the types of physical monuments that might be used to mark a site (Berry, 1983, ONWI-474; Kaplan, 1982, ONWI-354; Human Interference Task Force, 1984,

BMI/ONWI-537). Berry (1983, ONWI-474) concludes that materials of sufficient durability exist to construct monuments that will last 10,000 years at all proposed repository sites. Other possible permanent markers include geochemical or magnetic anomalies placed in deliberate patterns over the controlled area. Additional studies examined ways of ensuring that knowledge of a repository will be available to future generations through wide dissemination of records (Sebeok, 1984, BMI/ONWI-532; Tannenbaum, 1984, BMI/ONWI-535; Weitzberg, 1982, ONWI-379; Human Interference Task Force, 1984, BMI/ONWI-537). The DOE has not selected a preferred option for site marking at this time. A conceptual design of a repository marker system will accompany the DOE's application for a license to construct and operate a repository (10 CFR 60.21). A final design is required for a license amendment to close a repository (10 CFR 60.51).

The influence of possible disruptive events and processes, operating beyond the repository controlled area, is discussed in Section 6.4.2.6.

Assumptions and Data Uncertainty. It is assumed that during the repository operational period, incompatible activities, such as exploratory drilling, will be restricted at the site if such exploration or exploitation is believed to negatively affect repository performance. In the time period beyond, when operational controls have ceased to be effective, the permanent markers, records, and institutional controls will effectively prohibit exploration for, and exploitation of, any mineral resources within the controlled or surrounding area. The current uranium and vanadium data inventory in and near the site (Figure 3-40) provide a level of data that is insufficient to produce detailed resource and reserve value estimates and economic analyses. Expected remaining resources and reserves within the site are very small relative to similar sized areas elsewhere in southeastern Utah (Doelling, 1983; Merrell, 1983; Chenoweth, 1983).

Regarding potash, subsurface geologic analysis conducted to date utilizing geophysical logs and laboratory test data is insufficient to precisely define the potential for economic potash deposits and the western limit of potash deposits near the site. Despite the presently excessive depth to these potash deposits (greater than 1,341 meters [4,400 feet]), Hite (1982, p. 7) believed that these deposits could be considered for mining within the next 100 years. Since the thickness of the potential potash deposits in Salt Cycles 13 and 18 increases rapidly northward (away from the site), it is assumed that this thicker zone will attract exploration sometime in the future provided this is allowed by repository controls during the repository postclosure period. The thin, less than 3-meter- (less than 10-feet)-thick zone near the site will probably attract little, if any, exploration.

Regarding oil and gas, for the lower (evaporite-bearing) part of the Paradox Formation, it is assumed that zones of structural features such as fault zones and sharp folding are required to provide the fracture porosity necessary for a commercial oil or gas accumulation. For the upper (carbonate-bearing) part of the Paradox Formation, it is assumed that the economic concentrations of hydrocarbons are preferentially associated with regional structures that were active during Pennsylvanian Paradox deposition. The Leadville hydrocarbon accumulations are assumed to be controlled by a combination of structural and stratigraphic conditions.

Certain secondary influences, such as hydrodynamic gradients, may be important factors influencing the present location of hydrocarbon accumulations, particularly in stratigraphic zones of more continuous permeability, such as the Leadville Limestone. The extent of this influence is presently uncertain.

Evaluation of ground-water resources is based on all available literature and well data; these data are assumed to be representative of the candidate area.

Analysis. The known uranium and vanadium mine nearest the geologic repository operations area is a small production mine approximately 0.7 kilometer (0.4 mile) from the geologic repository operations area (Figure 3-40). All mining operations within the site are restricted to the Chinle Formation, which has been eroded away from most of the geologic repository operations area. Because no mines in the site vicinity have reported depths

greater than 24 meters (80 feet) (Table 3-11), any conceivable new discoveries within the Chinle or underlying Cutler Formations would be located stratigraphically at least 724 meters (2,375 feet) above the proposed Salt Cycle 6 repository layer. Because the expected uranium and vanadium reserves in this intensively explored area are limited, the potentially adverse impact of these mines on repository performance is judged to be minimal.

Regarding resource value, if the site area is withdrawn from permissible mineral exploration during the current institution-controlled part of a repository lifetime, the resulting denial of developable uranium and vanadium resources is judged to be minimal. This judgment is based on current expert judgments of remaining resources and distribution of known production in southeastern Utah. Similarly, the likelihood of human intrusion for uranium exploration and development, should that be allowed, is judged to be low.

An area of potential economic potash deposits at presently uneconomic depths of over 1,341 meters (4,400 feet) occurs northeast of and close to the geologic repository operations area. Any exploratory boreholes to develop these deposits in Salt Cycle 18 would pass through most of the Paradox Formation and the proposed repository layer in Salt Cycle 6. Such exploratory boreholes are unlikely to have a serious impact on repository performance, if drilled outside the repository controlled area (Section 6.4.2.6). Drilling within the controlled area is not anticipated because of the presence of permanent markers and wide dissemination of repository records. These deposits are currently considered economically unfeasible for development. During any future period when repository controls are not effective, the perceived potential value of the thin site-vicinity potash deposits will be low relative to the thicker and more extensive deposits to the north, east, and southeast. Therefore, the likelihood of potash exploration within the site vicinity during this future uncontrolled period is judged to be low, relative to other areas in the Paradox Basin.

Minor occurrences of iron oxide, sand and gravel, and formations suitable for dimension stone occur at or near the surface within the site vicinity. The iron oxide locality has been judged to be too small for commercial development (Section 3.2.8.2.3). Sand/gravel and dimension stone resources are widely available in southeastern Utah outside the candidate area. Because the site vicinity is so remote from any existing or currently foreseen market, the economic value of these site vicinity resources, being heavily dependent on transportation costs, is judged to be minimal.

No oil and gas production or significant oil and gas shows are presently known to occur within the site or its vicinity. A limited potential for small hydrocarbon accumulations exists in the upper Paradox and Honaker Trail formations in undiscovered stratigraphic traps only subtly associated with structure. Since untested structural or stratigraphic traps favorable for hydrocarbon accumulation are not known to exist in the site vicinity, the hydrocarbon potential of the site vicinity is judged to be very low compared to other areas in the Paradox Basin.

Potable ground-water resources and usage are limited within the site vicinity; such potable water is restricted to the upper part of thick permeable sandstone units that crop out across the site vicinity. Presently used wells are less than 122 meters (400 feet) deep. Because the known potable ground-water resource base is so limited, the probability of future ground-water development projects (such as large-scale withdrawal, extensive irrigation, underground pump storage or large-scale surface-water impoundments), that could significantly affect the ground-water flow system, is judged to be low. The halite deposits of the Paradox Formation occur at depths greater than 610 meters (2,000 feet) in the site vicinity (Section 3.2.3). The great depth of this salt, and the abundance of large, surface and near-surface sources of salt, make its economic value minimal.

The DOE recognizes the difficulty in speculating on the future exploration strategy that may be used in the long term for any commodity, regardless of the current evaluation of resource potential. Whatever the resource potential is perceived to be (now or in the future) for that period of the immediate future during which institutional controls, permanent markers, and records are maintained and enforced, the site will be protected from any deep drilling near enough to affect repository performance. During this period, such resources

that do exist will be denied exploitation. Based on the data presented in Section 3.2.8, the potential value of resources within the site vicinity (uranium/vanadium, potash, oil and gas, salt and potable water) is judged to be minimal and is not considered inviting for unacceptable postclosure intrusion.

Beyond this future period, it should be noted that the potential for conditions adverse to repository performance, caused by deep drilling for resources, can only occur after the institutional controls and the institutions enforcing them have ceased to exist, and all knowledge of the repository from records and permanent markers surrounding the site have disappeared; or alternately, if the surviving records and permanent markers are ignored. Thus, a severe setback in the course of civilization and subsequent recovery is presumed to be required for this scenario of accidental drilling intrusion for anticipated resources to occur. Even then, due to the presence of larger resources of uranium and vanadium, potash, and oil and gas to the north, east, and southeast of the site vicinity, within and beyond the candidate area, those larger resources would logically be drilled and exploited before the smaller resources within the site vicinity.

The time required for this scenario to completely develop (the institutional control period, the failure of civilization and its subsequent recovery to levels where it would be technically feasible to carry out drilling operations that could disturb the repository, and the initial exploitation of the larger resources outside the site vicinity) is probably longer than the minimum containment time of the repository.

6.3.1.8.2 Analysis of Favorable Condition.

(1) No known natural resources that have or are projected to have in the foreseeable future a value great enough to be considered a commercially extractable resource.

Evaluation. Uranium and vanadium deposits are present within the site; recorded production has occurred at one locality. In addition, potash deposits of commercial grade (but not commercial thickness) are present within the candidate area. Several miles north of the site, these potash beds are thicker and might be exploited at some future date when technology and economics allow for the mining of potash at greater depths than at present. Minor production of sand and gravel and potable water in the site vicinity has also occurred. Extensive halite deposits are present.

The evidence indicates that the favorable condition is not present.

(2) Ground water with 10,000 parts per million or more of total dissolved solids along any path of likely radionuclide travel from the host rock to the accessible environment.

Evaluation. Based on data gathered to date, the path of radionuclide travel from a repository in Salt Cycle 6 at this site could be upward or downward to the overlying or underlying interbed (Sections 3.3.1.2 and 6.3.1.1). Ground water within all evaporite and interbed layers is considered to be salt-saturated (TDS of 350,000 milligrams per liter) (Section 6.4.2.3.5). If travel continues upward to the Honaker Trail, the modal TDS content of that formation is 120,000 milligrams per liter. Travel downward from Salt Cycle 6 could reach the lower hydrostratigraphic unit. Available water quality data show total dissolved solids concentrations of 120,000 milligrams per liter and 103,473 milligrams per liter for the lower hydrostratigraphic unit (WCC, 1982, ONWI-290, Vol. II, Table 9-1).

The evidence indicates that the favorable condition is present.

6.3.1.8.3 Analysis of Potentially Adverse Conditions.

(1) Indications that the site contains naturally occurring materials, whether or not actually identified in such form that (i) economic extraction is potentially feasible during the foreseeable future or (ii) such

materials have a greater gross value, net value, or commercial potential than the average for other areas of similar size that are representative of, and located in, the geologic setting.

Evaluation. Extraction of uranium and vanadium ore, sand and gravel, and potable water has occurred in the recent past within the site. Extraction of sand and gravel and potable water has also occurred in the site vicinity. Extraction of potash within the site vicinity may or may not be feasible in the foreseeable future, but is more likely to occur in other areas of the Paradox Basin known to contain potash deposits that are more extensive and thicker than potash deposits in the site vicinity. For example, that part of the candidate area north of the site vicinity has, in Salt Cycle 18, potash beds nearly 8 times thicker 12 meters (40 feet) than at the GD-1 borehole near the site. Outside the candidate area to the north, potentially economic potash beds in Salt Cycle 13 that are probably more than 15 meters (more than 50 feet) thick, extend over an area of approximately 259 square kilometers (100 square miles) (Hite, 1976, p. 4). Similarly, to the southeast, potentially economic potash beds in Salt Cycle 18 are up to 11.3 meters (37 feet) thick and extend over an area exceeding 1,295 square kilometers (500 square miles) (in Utah and Colorado) (Hite, 1978, Figure 1).

Based on limited available data, expected uranium resources within the site are believed to be significantly lower than in areas of similar size and geology nearby and elsewhere in southeastern Utah. Potential potash resources within the site vicinity are less extensive than in similar size areas to the north and northeast (Figure 3-37). Potential hydrocarbon resources within the site vicinity are believed to be significantly less than in similar areas outside the site vicinity. None of the other resources discussed have greater potential within the site than outside. However, because potentially extractable resources do exist in the site vicinity, and because of the difficulty in speculating on resource development strategies of the future, it cannot be concluded that economic extraction of materials is not potentially feasible.

The evidence indicates that the potentially adverse condition is present.

(2) Evidence of subsurface mining or extraction for resources within the site if it could affect waste containment or isolation.

Evaluation. Existing uranium mines within the site extend to a maximum depth of 11 meters (35 feet) and are restricted to the Chinle Formation. Moreover, this formation has been eroded away from most of the geologic repository operations area. These present subsurface workings are judged not be extensive enough or deep enough to affect repository performance.

The evidence indicates that the potentially adverse condition is not present.

(3) Evidence of drilling within the site for any purpose other than repository-site evaluation to a depth sufficient to affect waste containment and isolation.

Evaluation. No drilling is known to have been done within the site. Of the 12 deep boreholes within the site vicinity, 6 penetrate through the potential repository salt layer. The nearest hydrocarbon exploration borehole to the geologic repository operations area is 8.4 kilometers (5.2 miles) away. The nearest hydrocarbon exploration borehole of appreciable depth is 8 kilometers (5 miles) from the geologic repository operations area boundary; the one repository evaluation borehole is 4.5 kilometers (2.8 miles) from the geologic repository operations area boundary (Figure 3-41).

The evidence indicates that the potentially adverse condition is not present.

(4) Evidence of a significant concentration of any naturally occurring material that is not widely available from other sources.

Evaluation. No significant concentrations of resources exist within the site vicinity that are not widely available elsewhere in southeastern Utah. Potash, by its nature of occurrence, is less widely available elsewhere than uranium and vanadium and other resources; however, as shown on Figure 3-37, most of the potentially economic deposits described by Hite (1982) are located north and east of the site.

The evidence indicates that the potentially adverse condition is not present.

(5) Potential for foreseeable human activities--such as ground-water withdrawal, extensive irrigation, subsurface injection of fluids, underground pumped storage, military activities, or the construction of large-scale surface-water impoundments--that could adversely change portions of the ground-water flow system important to waste isolation.

Evaluation. Because of limited potable ground water and surface resources and usage within and near the site, none of the activities mentioned in the above condition are expected at the site, including future large-scale ground-water development projects that might have adverse effects on the ground-water flow system; e.g. reduction of ground-water travel times from pre-waste-emplacement conditions.

The evidence indicates that the potentially adverse condition is not present.

6.3.1.8.4 Analysis of Disqualifying Condition

A site shall be disqualified--

(1) If 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.

Evaluation. The maximum depth of known mine workings within the site is 24 meters (80 feet); the proposed repository horizon is at a depth of 893 meters (2,930 feet). The closest deep exploration borehole that penetrates near or through the proposed repository horizon is 8 kilometers (5 miles) from the geologic repository operations area. Based on these data, it is judged that none of the known exploration boreholes or mine excavations have created significant pathways between the subsurface facility and the accessible environment.

The evidence does not support a finding that the site is disqualified (Level 1).

(2) Ongoing or likely future activities to recover presently valuable natural mineral resources outside the controlled area would be expected to lead to an inadvertent loss of waste isolation.

Evaluation. There are no ongoing mineral activities outside the controlled area (site) and within the site vicinity, other than sporadic assessment work and occasional small production mining at near-surface uranium and vanadium deposits located approximately 884 meters (2,900 feet) above the proposed repository horizon. The only future activity that might lead to an inadvertent loss of waste isolation is deep drilling for potash or oil and gas within the site vicinity. Since the potential potash resources north and east of the site vicinity are thick and substantial, and while these resources within the site vicinity are small and of less-than-commercial thickness (Section 3.2.8.2.2), it is expected that the thicker resources would be exploited by drilling first during any future condition of potash scarcity. Similarly, due to the expected very low potential of hydrocarbon resources within the site vicinity, in comparison to other areas southeast and east in the Paradox Basin Section 3.2.8.1), it is likely that future oil and gas drilling will occur outside rather than within the site vicinity. Exploitation of halite resources is considered unlikely. Thus, it is believed that, due to the lack of anticipated commercial resources in the site vicinity, it is unlikely that deep drilling will occur here. Drilling within the controlled area is not expected because of the presence of permanent markers and wide dissemination of repository

records. Additional planned boreholes in the repository evaluation program will provide important data for the reevaluation of this future development potential.

The evidence does not support a finding that the site is disqualified (Level 1).

6.3.1.8.5 Conclusion for the Qualifying Condition. The preceding discussion has shown that expected exploration for, or development of, natural resources at or near the site is judged not likely to adversely affect repository performance.

The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

Table 6-10 summarizes the evaluations and findings for the postclosure Technical Guidelines requiring site characterization.

6.3.2 Postclosure System Guideline, 10 CFR 960.4-1

The postclosure System Guideline requires compliance with those EPA and NRC regulations that are intended to ensure that the health and safety of the public and the quality of the environment will be protected.

This section evaluates Davis Canyon with regard to the postclosure System Guideline for performance of the natural and engineered barriers. The evaluation is made in the context of the related Technical Guidelines, evaluated individually in Section 6.3.1, and the performance assessments of the engineered barriers presented in Section 6.4.2.

Because the site has not been characterized, the complete data base needed for conclusive evaluation of this guideline is unavailable. The present evaluations are preliminary and are for the purpose of selecting sites for further characterization. The likelihood of the site meeting the guideline is judged from the presently available information, using appropriate and technically conservative assumptions.

Following presentation of the qualifying condition in Section 6.3.2.1, the process used in its evaluation is described in Section 6.3.2.2. Performance of the engineered-barrier system and the geologic setting are discussed in Sections 6.3.2.3 and 6.3.2.4, respectively. Conclusions are provided in Section 6.3.2.5. The evaluations and findings are summarized in a Table 6-10.

6.3.2.1 Statement of Qualifying Condition

> The geologic setting at the site shall allow for the physical separation of radioactive waste from the accessible environment after closure in accordance with the requirements of 40 CFR Part 191, Subpart B, as implemented by the provisions of 10 CFR Part 60. The geologic setting at the site will allow for the use of engineered barriers to ensure compliance with the requirements of 40 CFR Part 191 and 10 CFR Part 60 (see Appendix I of this Part).

This guideline is the postclosure System Guideline. Its purpose is to help ensure that a geologic repository will perform in accordance with applicable standards and regulations. The System Guideline for postclosure performance particularly addresses the need to ensure protection of public health and safety from radioactive waste materials for at least 10,000 years. It incorporates relevant parts of the EPA and NRC regulations: (1) the EPA limits on release of radionuclides to the accessible environment (40 CFR Part 191), and (2) the NRC site criteria (10 CFR Part 60).

This guideline addresses the entire repository system, including the geologic setting as well as the engineered features of the waste form, waste packages, and other repository elements. Following the classification in 10 CFR Part 60.113, the "engineered-barrier system" comprises the various engineered features in the repository. These are distinguished from the

natural barriers in the geologic setting. The two sets of barriers combine to form the repository system.

Performance standards for the various aspects of the geologic setting are provided in the technical guidelines relating to the postclosure System Guideline. Specific Technical Guidelines address geohydrology, geochemistry, rock characteristics, climatic changes, erosion, dissolution, tectonics, and human interference.

6.3.2.2 Evaluation Process

The evaluation of the system using the postclosure System Guideline is augmented by the use of the related Technical Guidelines addressing the geologic setting (Section 6.3.1). Performance assessments (Section 6.4.2) are used to investigate potential systems effects of selected conditions, processes, and events in the geologic setting and to evaluate elements of the engineered-barrier system. Performance assessments are also used to evaluate compliance with 40 CFR Part 191 by calculating expected release rates of various radionuclides (Section 6.4.2.4).

This evaluation process consists of addressing the expected performance of each barrier individually and then assessing its potential contribution to overall repository performance. For site evaluation, primary emphasis is on the waste-isolation capabilities of the natural barriers in the geologic setting. The engineered-barrier system is not relied upon to compensate for deficiencies that may be identified in the natural barriers.

The performance assessments of engineered barriers indicate the likelihood of complying with 10 CFR Part 60 criteria, based on the site-specific data presently available. Waste package life (Section 6.4.2.3.3) is analyzed, based on expected thermal conditions (Section 6.4.2.3.1) and on the conservative estimates of quantities of brine assumed to contact the package (Section 6.4.2.3.2). Solubility of the waste form (Section 6.4.2.3.4), performance of shaft seals (Section 6.4.2.3.5), and combined performance of the engineered-barrier system (Section 6.4.2.3.4) are also evaluated for potential compliance with the 10 CFR Part 60 criteria. In the absence of site-specific designs, the performance assessments address existing concepts for the engineered features of a repository. These are considered to be adequate representations for this preliminary assessment.

Evaluation of the geologic setting is based on the findings with regard to the individual Technical Guidelines, as discussed in Section 6.3.1 and summarized in Table 6-10. The effect of individual guidelines on overall system performance is addressed by considering the findings of the favorable and potentially adverse conditions.

The relevant data and assumptions used for the evaluations of individual Technical Guidelines and for the performance assessments are described in the related parts of Sections 6.3.1 and 6.4.2. The individual discussions also describe the uncertainties and limitations in the available data.

6.3.2.3 Engineered Barrier System

The engineered barrier system is evaluated to determine the likelihood that the present conceptual designs can comply with 10 CFR Part 60 criteria under the expected site conditions. The two criteria addressed are (1) waste package life, and (2) releases from the engineered-barrier system.

6.3.2.3.1 Waste Package Lifetime. Waste package lifetime will be a function largely of the rate of corrosion and external stress. Corrosion rates will be determined by the overpack material properties, the ambient emplacement temperature, and the amount and chemistry of the contact fluids. In salt, the quantity of contact fluids is likely to be small. It is assumed that the sources of contact water are that which is presently contained in the salt, and that which could arise from clays, etc. External stress is assumed to be determined largely by lithostatic pressures, a function of repository horizon depth. Preliminary assessment of the performance of the waste package is discussed in Section 6.4.2.3.3. The processes leading to package failure are also described in Section 6.4.2.3.

Lifetimes were estimated for a range of fluid contact scenarios, including the very conservative assumption that brine flow quantities were unlimited). Under expected conditions where limited brine quantities are used, the corrosion process becomes self-limiting and lifetimes can reasonably be expected to exceed 10,000 years (Section 6.4.2.3.3), which are considerably in excess of the 300 to 1,000 year requirement.

6.3.2.3.2 Engineered Barriers. As indicated by the waste package lifetime analysis, the "release rate" of radionuclides into the host rock is expected to be zero for at least 10,000 years, because failure of the waste package is not likely during that period. In order to analyze the effectiveness of the remainder of the engineered-barrier system, analyses have been performed assuming package containment failure at 300 years (Section 6.4.2.3.4). The results of these calculations, which depend on brine flow rates and solubility constraints, are given in Section 6.4.2.3.4 for commercial high-level waste (CHLW) and for the spent fuel from pressurized water reactors (SFPWR) package at the NRC-mandated minimum package lifetime of 300 years. Assuming (1) no thermal gradient threshold for brine migration, (2) no brine consumed by chemical reaction beyond 300 years, and (3) package failure at 300 years, these calculations indicate that cesium-137 will be the limiting radionuclide. With an interim waste form specification of 10^{-4} fractional release per year (ONWI, 1983, ONWI-462, p. 11), a package lifetime of only 430 years (as compared to the expected life in excess of 10,000 years) would be required to enable the release rate limits for the engineered-barrier system to be met.

In effect, what this analysis of performance limits indicates is that the 10 CFR Part 60 release rate requirement for the engineered-barrier system cannot be assured by only a carbon steel container with a lifetime of 300 years. On the other hand, the requirements can be met with a package having a minimum lifetime of 430 years and a waste form that would not release radionuclides upon brine contact at a rate greater than 10^{-4} fractional release per year (Section 6.4.2.3.4).

In fact, waste package designs are expected to display features that withstand a greater than 430-year performance lifetime and leach-resistant waste forms. While either of these additional release-limiting features appears to be sufficient to satisfy requirements, in fact, both are expected to be present in the repository. Therefore, it appears likely that the release limit requirements for the engineered-barrier system can be met.

6.3.2.4 Geologic Setting

This section summarizes evaluations of the eight postclosure Technical Guidelines in relation to overall assessment of the System Guideline, based on the more detailed discussions in Section 6.3.1. Davis Canyon is considered to be qualified for further consideration because all of the qualifying conditions are found while none of the disqualifying conditions are present. Accordingly, the emphasis in this section is on considering the balance of favorable and potentially adverse conditions that have been identified.

Geohydrology. The qualifying condition was found for Davis Canyon because the probability (see Section 6.4.2.3.5) of ground-water travel times to the accessible environment being less than 1,000 years is extremely low, the salt has very low hydraulic conductivity, hydrologic processes are not expected to reduce isolation capability, and there are no potable water sources along likely flow paths to the accessible environment. The disqualifying condition is not found because of the long ground-water travel time in the salt and the primary porosity zones in the surrounding aquifers.

The favorable condition concerning a geohydrologic system that can be readily characterized and modeled was not found to be present because of the limited data base and the preliminary state of model development.

The potentially adverse condition concerning the presence of features in the geologic setting that could contribute to difficulty in characterizing and modeling the geohydrologic system was found to be present.

This must be qualified due to finding a lack of site-specific data. Because all other favorable conditions were found and none of the other potentially adverse conditions were found, the qualifying condition was expected to be met.

Geochemistry. The qualifying condition is expected to be found for Davis Canyon because the salt has relatively low water content. One favorable condition was not found to be present because of insufficient data to determine a numerical value for retardation of radionuclides. No potentially adverse conditions were identified, but geochemical conditions are not known with confidence because site characterization has not been performed. The uncertainties regarding geochemistry do not reduce confidence in the isolation capabilities of the geologic setting because of the very long ground-water travel times to the accessible environment.

Rock Characteristics. The qualifying condition is found for Davis Canyon. The salt provides sufficient thickness and lateral extent for the subsurface facility. The salt is considered particularly well suited for construction of the subsurface facility and for accommodating the thermal, chemical, mechanical, and radiation stresses induced by radioactive waste. One potentially adverse condition was found to be present regarding rock characteristics, because brine migration is anticipated to occur.

Climate Change. The qualifying condition is expected to be found because future climate conditions are not likely to lead to radionuclide releases greater than allowable limits. The second favorable condition was not found to be present because it is not possible to state that no measurable changes occurred to the hydrologic system as a result of climatic changes during the Quaternary. No potentially adverse conditions have been identified.

The uncertainty with regard to the qualifying condition, which specifically indicates that climatic conditions will not lead to radionuclide releases greater than those allowed under existing requirements, is the result of the lack of analyses.

Erosion. The qualifying condition is found for the erosion Technical Guideline. The repository level is to be at a depth greater than 885 meters (2,900 feet) and overburden is projected to remain in excess of the 200-meter (656-feet) minimum even after 1,000,000 years of erosion. The favorable conditions are all present. No potentially adverse conditions are identified, and the disqualifying condition is not found.

Dissolution. The qualifying condition is expected to be found. The closest potential dissolution feature is 16 kilometers (10 miles) from the site. The favorable condition is present and the potentially adverse condition was found to be present. The latter condition was found because dissolution has been identified within the geologic setting. The disqualifying condition was not found. Uncertainty with regard to the qualifying condition results from a lack of site-specific information.

Tectonics. The qualifying condition is found, and the disqualifying condition is not found. Davis Canyon is in a relatively stable tectonic setting. One potentially adverse condition is found to be present in that tectonic processes have been operating in the geologic setting during the Quaternary Period. However, evaluations of the geohydrology and erosion Technical Guidelines indicate that the predicted rates of tectonic processes would not adversely affect ground-water movement or cause excessive erosion.

Human Interference. The qualifying condition is expected to be found and the disqualifying condition is not found. Although potential resources are present at Davis Canyon and exploration has occurred in the surrounding area, previous activities have not created pathways between the subsurface facility and the accessible environment. Future penetrations to create such pathways are considered unlikely, based on the use of permanent markers to identify the site, the limited resources present, and the abundance of such resources in this and other geologic settings. The uncertainty with regard to the qualifying condition results from the lack of specific data concerning the potential economic resources at the site.

6.3.2.5 Conclusion

Davis Canyon is found to meet the qualifying condition for the postclosure System Guideline, based on evaluations of the related Technical Guidelines, performance assessments of the engineered-barrier system, and calculations of expected radionuclide release rates. Davis Canyon was found to meet the qualifying conditions in the postclosure Technical Guidelines and none of the disqualifying conditions were found. The potentially adverse conditions that are found would be compensated for by the favorable conditions. Performance assessments, based on the present design concepts for the engineered-barrier system, indicate that the 10 CFR Part 60 criteria would be met at Davis Canyon. Expected radionuclide releases have been calculated and would comply with 40 CFR Part 191.

The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

Table 6-14 summarizes the evaluations and findings for the postclosure System Guidelines requiring site characterization.

6.3.3 Preclosure Technical Guidelines, 10 CFR 960.5-2

The Technical Guidelines in this section present the conditions for the characteristics, processes, and events that influence site suitability relative to the preclosure System Guidelines. The specific factors considered here include the surface conditions of the site, the host rock and surrounding strata, hydrology, and tectonics. The site is evaluated against these conditions in terms of its ability to accommodate the repository and its attendant activities, while ensuring the health and safety of personnel.

6.3.3.1 Surface Characteristics, Guideline 10 CFR 960.5-2-8

The preclosure guideline on surface characteristics is concerned with conditions that are important to the ease and cost of constructing, operating, and closing a repository. In sites that are prone to periodic flooding, are located in a rugged terrain, or have other adverse surface features, special measures may be necessary for repository construction, operation, and closure. The cost of repository construction, operation, and closure could rise to prohibitive levels if a large number of special measures were necessary for these phases. However, other features of the site--those that would significantly enhance waste isolation--could be more important than the higher costs associated with adverse surface characteristics.

This guideline includes a qualifying condition, two favorable conditions, and one potentially adverse condition for analysis. It does not have a disqualifying condition.

6.3.3.1.1 Statement of Qualifying Condition.

> The site shall be located such that, considering the surface characteristics and conditions of the site and surrounding area, including surface-water systems and the terrain, the requirements specified in Section 960.5-1(a)(3) can be met during repository siting, construction, operation, and closure.

Evaluation Process. To determine whether the Qualifying Condition with respect to the surface characteristics specified in 10 CFR 960.5-2-8 can be met, relevant data are summarized and evaluated. Assumptions and uncertainties are discussed and a brief analysis is provided. Evaluations are made regarding favorable and potentially adverse conditions at the site. These conditions and findings are summarized in Table 6-15. Conclusions drawn with respect to qualification of the site for further consideration as a potential repository are presented along with a rationale for these conclusions. Cross referencing is provided to other sections of the report.

Relevant Data. Repository surface facilities will be located in a relatively level side canyon in a small ephemeral wash near the mouth of Davis Canyon (Figure 5-2). The floor of

Table 6-14. Postclosure System Guideline Considerations Requiring Site Characterization, Davis Canyon

System Guideline 960.4-1(a)	Associated Technical Guidelines	Assessment Results	Findings
Qualifying Condition.			
The geologic setting at the site shall allow for the physical separation of radioactive waste from the accessible environment after closure in accordance with the requirements of 40 CFR Part 191, Subpart B, as implemented by the provisions of 10 CFR Part 60. The geologic setting at the site will allow for the use of engineered barriers to ensure compliance with the requirements of 40 CFR Part 191 and 10 CFR Part 60 (see Appendix I of this Part).	Geohydrology - 960.4-2-1 Geochemistry - 960.4-2-2 Rock Characteristics - 960.4-2-3 Climatic Changes - 960-4-2-4 Erosion - 960.4-2-5 Dissolution - 960.4-2-6 Tectonics - 960.4-2-7 Human Interference - 960.4-2-8	System Guideline: The qualifying conditions with respect to postclosure system performance requirements can be met. This conclusion is one of reasonable assurance based upon assessments of what is currently known about the geohydrologic setting and the characteristics of host rock and surrounding geologic structures. Engineering feasibility as shown by conceptual design of the facility and waste package and predicted performance of the repository, both short-term and long-term, provides sufficient confidence in the site's potential to support nomination of the site for further detailed studies. The results of those studies must be known, and substantial additional engineering design and performance assessment must be done before this system qualifying condition can be affirmed and used as a repository proposal.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
	Geohydrology (Section 6.3.1.1)	Technical Guidelines: The site is expected to meet this condition because the probability that groundwater travel time to the accessible environment greatly exceeds the favorable condition of 10,000 years is very high. This assessment is made using conservative values for hydraulic parameters, and no adjustment is made for radionuclide retardation.	
	Geochemistry (Section 6.3.1.2)	Assessments of waste package corrosion show that the engineered barrier system will contain radionuclides for at least 10,000 years under expected conditions.	

Table 6-14. Postclosure System Guideline Considerations Requiring Site Characterization, Davis Canyon
(Page 2 of 2)

System Guideline 960.4-1(a)	Associated Technical Guidelines	Assessment Results	Findings
	Rock Characteristics (Section 6.3.1.3)	The host rock and surrounding units are capable of withstanding the thermal, chemical, mechanical, and radiation stresses expected to be induced by repository construction, operation, and closure.	
	Climatic Changes (Section 6.3.1.4)	Climatic changes are expected to be the same as those sustained during the Quaternary. The effects on rates of erosion and salt dissolution are encompassed in estimated Quaternary rates; these have an insignificant impact.	
	Erosion (Section 6.3.1.5)	Based on projections of Quaternary conditions, no radionuclide releases directly attributable to erosion are expected in less than a million years.	
	Dissolution (Section 6.3.1.6)	Based on projections of assumed rates of dissolution, it will not reach the repository within a period longer than 10,000 years.	
	Tectonics (Section 6.1.3.7)	The nature and rates of tectonic processes and events show that there is very little likelihood of disruptive tectonic events during the next 10,000 years at the site.	
	Human Interference/ Natural Resources (Section 6.3.1.8)	Usable ground water at the site is limited. Extraction of water will not adversely affect waste isolation. The potential for undiscovered hydrocarbon resources is low, and the potential is low for the occurrence and development at the site of other mineral resources.	

the side canyon slopes downward to the southeast at a gentle rate of approximately 2 percent. Surficial (near-surface) materials consist of a veneer of soil overlying bedrock. The thickness of soil ranges from zero to a maximum of approximately 5 meters (15 feet). A more detailed description of the topography at and around the site is presented in Section 3.2.2.1.

A portion of the access road and railroad alignments are located in rugged terrain east and northeast of the site. These areas are deeply incised by drainage courses and canyons. Canyon walls are steep, with maximum heights of approximately 305 meters (1,000 feet).

Water runoff from the proposed surface facility site drains into the small ephemeral wash at the mouth of the side canyon, which in turn drains into the Davis Canyon tributary. Based on available information, the probable maximum flood (PMF) floodplain for the small wash includes a portion of the site (BGI, 1983, ONWI-476) (Figure 3-51). However, shaft collar, other safety-related facilities, and most other surface facilities will be located outside the flood plain.

The nearest surface-water impoundment is a 2- to 4-hectare (5- to 10-acre) irrigation pond on Indian Creek at the Dugout Ranch, approximately 6 kilometers (4 miles) southeast of the site. Any quantity of water released from the pond will flow within the confines of Indian Creek and pass an area approximately 1.6 kilometers (1 mile) to the northeast. No other impoundments lie upstream from the site.

Assumptions and Data Uncertainties. Uncertainties are associated with the estimate of the maximum probable flood and engineering interpretations made from topographic maps which have 24.4-meter (80-foot) contour lines. The estimates for cut and fill at the repository site and along the transportation routes are based on these maps which allow only estimates for preliminary engineering purposes. Also, the flooding evaluation is based on these maps and non-site-specific data (Section 3.3.1.4).

It is assumed that the areas of the site that are located on the PMF floodplain will be filled to an elevation above the PMF floodplain, and that control channels will be constructed to direct flow around the site. It is also assumed that standard engineering practice can be used to design and build railroad and highway corridors to the site through rugged terrain.

Analysis. A portion of the geologic repository operations area falls within the PMF flood plain. This portion of the site can be brought above the floodplain elevation by placement of fill during construction. In addition, floodwaters can be diverted around the site by the construction of a lined flood-control channel.

Information on the surficial (near-surface) subgrade materials (soil and rock) within the site is summarized in Section 3.2.9. Soils appear to be acceptable for large grading operations. Excavation to establish grades and structure foundations will encounter bedrock. Blasting of the bedrock will be required to excavate it. No unacceptable foundation conditions are expected, based on available information.

The construction of the access road and railroad through the rugged terrain will be difficult and expensive relative to a site in a terrain of low relief. However, standard practice in the design and construction of these routes will allow potential sources of hazard such as steep grades, sharp switchbacks, and slope instability to be mitigated.

6.3.3.1.2 Analysis of Favorable Conditions.

(1) Generally flat terrain.

Evaluation. Figure 3-2 shows site topography, and Figure 5-9 shows the proposed transportation routes. The Paradox Basin in general and the candidate area in particular is noted for steep canyons and rugged terrain. Although the terrain at the surface facility is relatively flat, much of the surrounding area, in particular the terrain through which the access road and railroad will be constructed, is rugged.

Table 6-15. Preclosure Technical Guidelines Requiring Site Characterization, Davis Canyon

Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
Surface Characteristics	960.5-2-8	6.3.3.1		
(a) Qualifying Condition				
The site shall be located such that, considering the surface characteristics and conditions of the site and surrounding area, including surface-water systems and the terrain, the requirements specified in Section 960.5-1(a)(3) can be met during repository siting, construction, operation, and closure.			The specified requirements can be met considering surface characteristics.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
(b) Favorable Condition				
(1) Generally flat terrain.			The access routes cross very rugged terrain.	The evidence indicates that a favorable condition is not present.
(2) Generally well-drained terrain.			The site and vicinity is very well drained.	The evidence indicates that a favorable condition is present.
(c) Potentially Adverse Condition				
Surface characteristics that could lead to the flooding of surface or underground facilities by the occupancy and modification of flood plains, the failure of existing or planned engineered surface-water impoundments, or the failure of engineered components of the repository.			Portions of the proposed site are located in the flood plain; however, consideration of appropriate design measures has not been taken into account.	The evidence indicates that a potentially adverse condition is present.
Rock Characteristics	960.5-2-9	6.3.3.2		
(a) Qualifying Condition				
The site shall be located such that (1) the thickness and lateral extent and the characteristics and composition of the host rock will be suitable for accommodation of the underground facility; (2) the repository construction, operation, and closure will not cause undue hazard to personnel; and (3) the requirements specified in Section 960.5-1(a)(3) can be met.			Based on available information there is adequate thickness, and sufficient lateral extent of host rock with the appropriate composition to safely construct, operate, and close a repository.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
(b) Favorable Conditions				
(1) A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the underground facility.			The host rock is expected to be approximately 200 feet thick over an area considerably larger than the site.	The evidence indicates that a favorable condition is present.
(2) A host rock with characteristics that would require minimal or no artificial support for underground openings to ensure safe repository construction, operation, and closure.			Based on existing data, it is difficult to estimate the artificial support requirements for underground openings especially in the early stages of heating. Additionally, it is not possible to estimate the support	The evidence indictaes that a favorable condition is not present.

Table 6-15. Preclosure Technical Guidelines Requiring Site Characterization, Davis Canyon
(Page 2 of 4)

Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
			requirements for retrieval, which for this evaluation have been considered part of repository operations as defined in 10 CFR 960.2.	
(c) Potentially Adverse Conditions				
(1) A host rock that is suitable for repository construction, operation, and closure, but is so thin or laterally restricted that little flexibility is available for selecting the depth, configuration, or location of an underground facility.			The host rock is expected to be approximately 200 feet thick. There is a potential for minor amounts of carnallite to be present which could influence the degree of flexibility in locating the repository within the vertical extent of the salt cycle.	The evidence indicates that a potentially adverse condition is not present.
(2) In situ characteristics and conditions that could require engineering measures beyond reasonably available technology in the construction of the shafts and underground facility.			Based on existing data no complex engineering measures would be required.	The evidence indicates that a potentially adverse condition is not present.
(3) Geomechanical properties that could necessitate extensive maintenance of the construction of the shafts and underground facility.			Existing data indicate maintenance might be required. Additionally, it is not possible to estimate the support requirements for retrieval, which is considered part of repository operations as defined in 10 CFR 960.2.	The evidence indicates that a potentially adverse condition is present.
(4) Potential for such phenomena as thermally-induced fracturing, the hydration and dehydration of mineral components, or other physical, chemical, or radiation-related phenomena that could lead to safety hazards or difficulty in retrieval during repository operation.			Several rock characteristics could potentially lead to difficulty in retrieval of the waste. Also, retrieval of canisters in the presence of radiation could pose operational problems.	The evidence indicates that a potentially adverse condition is present.
(5) Existing faults, shear zones, pressurised brine pockets, dissolution effects, or other stratigraphic or structural features that could compromise the safety of repository personnel because of water inflow or construction problems.			Brine pockets may be encountered in the repository.	The evidence indicates that a potentially adverse condition is present.
(d) Disqualifying Condition				
The site shall be disqualified if the rock characteristics are such that the activities associated with repository construction, operation, or closure are predicted to cause significant risk to the health and safety of personnel, taking into account mitigating measures that use reasonably available technology.			Based on existing data which have been gathered from the surface, the rock characteristics appear to be such that the repository could be built, operated, and closed safely.	Ine evidence does not support a finding that the site is disqualified (Level 1).
Hydrology	960.5-2-10	6.3.3.3		
(a) Qualifying Condition				
The site shall be located such that the geohydrologic setting of the site will			Low permeabilities of the host rock and surrounding units and presence of relatively	The evidence does not support a finding that the site is not likely to meet the qualifying condition

Table 6-15. Preclosure Technical Guidelines Requiring Site Characterization, Davis Canyon
(Page 3 of 4)

Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(1) be compatible with the activities required for repository construction, operation, and closure; (2) not compromise the intended functions of the shaft liners and seals; and (3) permit the requirements specified in Section 960.5-1(1)(3) to be met.			dry strata from the surface to the repository indicate a compatible geohydrologic setting for the repository.	(Level 3).
(b) Favorable Condition				
(1) Absence of aquifers between the host rock and the land surface.			The Elephant Canyon Formation, which is a low yield aquifer, is located between the host rock and land surface.	The evidence indicates that a favorable condition is not present.
(2) Absence of surface-water systems that could potentially cause flooding of the repository.			Based on the analysis of existing data, there is a potential for flooding at the site.	The evidence indicates that a favorable condition is not present.
(3) Availability of the water required for repository construction, operation, and closure.			Water appears to be available from the San Juan Water Conservancy District.	The evidence indicates that a favorable condition is present.
(c) Potentially Adverse Condition				
Ground-water conditions that could require complex engineering measures that are beyond reasonably available technology for repository construction, operation, and closure.			Hydrologic data from the GD-1 borehole indicate suitable hydrologic conditions for the construction, operation, and closure of the repository.	The evidence indicates that a potentially adverse condition is not present.
(d) Disqualifying Condition				
A site shall be disqualified if, based on expected ground-water conditions, it is likely that engineering measures that are beyond reasonably available technology will be required for exploratory-shaft construction or for repository construction, operation, or closure.			Low permeability strata comprise the rock mass within and above the repository horizon. Control of the samll quantities of water into a shaft during construction is expected to be achieved using standard engineering and construction practices.	The evidence does not support a finding that the site is disqualified (Level 1).
Tectonics	960.5-2-11	6.3.3.4		
(a) Qualifying Condition				
The site shall be located in a geologic setting in which any projected effects of expected tectonic phenomena or igneous activity on repository construction, operation, or closure will be such that the requirements specified in Section 960.5-1 (a)(3) can be met.			Quaternary history of the site and vicinity has been dominated by regional uplift, and there has been no igneous activity. Seismic hazard is moderate requiring no unreasonable costs for mitigation.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
(b) Favorable Conditions				
The nature and rates of faulting, if any, within the geologic setting are such that the magnitude and intensity of the associated seismicity are significantly less that those generally allowable for the construction and operation of nuclear facilities.			The magnitude and intensity of seismicity associated with faulting in the geologic setting is estimated to be greater than that generally allowable at other nuclear facilities.	The evidence indicates that a favorable condition is not present.

Table 6-15. Preclosure Technical Guidelines Requiring Site Characterization, Davis Canyon
(Page 4 of 4)

Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(c) Potentially Adverse Conditions				
(1) Evidence of active faulting within the geologic setting.			There are several faults near the site that may have been active during the Quaternary.	The evidence indicates that a potentially adverse condition is present.
(2) Historical earthquakes or past human-induced seismicity that, if either were to recur, could produce ground motion at the site in excess of reasonable design limits.			The seismic record does not indicate the need for excessive design requirements.	The evidence indicates that a potentially adverse condition is not present.
(3) Evidence, based on correlations of earthquakes with tectonic processes and features (e.g., faults) within the geologic setting, that the magnitude of earthquakes at the site during repository construction, operation, and closure may be larger than predicted from historical seismicity.			Although the south Shay Graben fault could produce an earthquake larger than any historically observed, such movement is judged unlikely in the next 50 years.	The evidence indicates that a potentially adverse condition is not present.
(3) Disqualifying Condition				
A site shall be disqualified if, based on the expected nature and rates of fault movement or other ground motion, it is likely that engineering measures that are beyond reasonably available technology will be required for exploratory-shaft construction or for repository construction, operation, or closure.			The nature and rates of ground motion expected from potential sources identified for the site are expected to be accommodated by application of available engineering technology.	The evidence does not support a finding that the site is disqualified (Level 1).

The evidence indicates that the favorable condition is not present.

(2) Generally well-drained terrain.

Evaluation. As a result of the well-developed drainage pattern, the site area drains freely. The rugged topography, discussed above, provides excellent drainage for the site. Engineered drainage established during site construction will assure that this favorable condition is maintained by rechanneling existing drainage around the surface facilities. In addition, soils at the site drain freely. Parent materials are primarily sandstones and siltstones which result in the development of soils that have low water retention properties (Section 3.2.9).

The evidence indicates that the favorable condition is present.

6.3.3.1.3 Analysis of Potentially Adverse Conditions.

> Surface characteristics that could lead to the flooding of surface or underground facilities by the occupancy and modification of flood plains, the failure of existing or planned man-made surface-water impoundments, or the failure of engineered components of the repository.

Evaluation. As discussed in Section 3.3.1.4 and shown on Figure 3-51, the 100-year and PMF floodplains in Davis Canyon cross the geologic repository operations area, and the repository surface facilities occupy the floodplains. No surface-water impoundments exist whose failure could flood the surface facility. No known surface characteristics exist that could lead to failure of the engineered components of the repository.

The mitigation of floodplains by placement of fill during construction is a common engineering technique to ensure that surface facilities are not jeopardized. However, for purposes of this evaluation, no consideration is given to such mitigation measures.

The evidence indicates that the potentially adverse condition is present.

6.3.3.1.4 Analysis of Disqualifying Conditions. The surface characteristics guideline has no disqualifying condition; therefore, an analysis is not presented.

6.3.3.1.5 Conclusion for the Qualifying Condition. One favorable condition was not present and the potentially adverse condition is present. Primary concern is in regard to the construction of railroad and highway access to the site in the evaluation of the favorable condition. While the condition was not found to be present, transportation corridors, both rail and road, have been built in similar areas throughout the western United States.

A relatively flat, well-drained surface-facility location with freely draining soils results in meeting the qualifying condition. Mitigation, however, would require greater construction costs.

The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.3.3.2 Rock Characteristics, Guideline 10 CFR 960.5-2-9

The objective of the preclosure guideline on rock characteristics is to ensure that due consideration is given to those characteristics of the host rock that may affect (1) the ease and cost of repository construction, operation, and closure; and (2) the safety of repository workers. Among those characteristics are the thickness and lateral extent of the host rock, geomechanical properties that are favorable for the maintenance of subsurface openings, and conditions that would allow the construction of shafts and the subsurface facility with reasonably available technology.

This guideline includes a qualifying condition, two favorable conditions, and five potentially adverse conditions for analysis. It also has one disqualifying condition.

6.3.3.2.1 Statement of Qualifying Condition.

> The site shall be located such that (1) the thickness and lateral extent and the characteristics and composition of the host rock will be suitable for accommodation of the underground facility; (2) repository construction, operation, and closure will not cause undue hazard to personnel; and (3) the requirements specified in Section 960.5-1(a)(3) can be met.

Evaluation Process. To determine whether the qualifying condition with respect to rock characteristics specified in 10 CFR 960.5-2-9 can be met, relevant data (discussed in detail in Sections 3 and 5) are summarized and evaluated. Assumptions and uncertainties are discussed and a brief analysis is provided. Evaluations are made as to whether favorable or potentially adverse conditions exist at the site. These conditions and findings are summarized in Table 6-15. Conclusions drawn, with respect to qualifying the site for further consideration as a potential repository, are presented along with the rationale for these conclusions.

Relevant Data. The relevant rock properties data are the same as described in Section 6.3.1 for postclosure Technical Guidelines. As described in Section 3.4.1, the GD-1 borehole, approximately 5 kilometers (3 miles) from the geologic repository operations area, indicates that Salt Cycle 6 is 73 meters (240 feet) thick at a depth of 950 meters (3,115 feet) below the surface (WCC, 1982, ONWI-290, Vol. II, Figure 5-3). Ten other boreholes in the candidate area and seismic reflection data indicate that Salt Cycle 6 maintains a minimum thickness of 30 meters (100 feet) for a minimum of 8 kilometers (5 miles) in any direction from the site, and a minimum thickness of 55 meters (180 feet) within the site boundaries (WCC, 1982, ONWI-290, Vol. II, Figure 5-13), and at a depth of 910 meters (2,985 feet).

Strength measurements conducted on core from GD-1 indicate that the measured salt strength is sufficient for a repository design that will generally employ factors of safety in excess of two (SCC, 1984, p. 5-4). Creep tests from GD-1 salt indicate that the salt will creep at expected stress and temperature levels to seal excavations and fractures after waste emplacement (Section 3.2.6.1). Thermal property determinations from GD-1 salt and nonsalt (Section 3.2.6.2) show that thermal conductivity is within expected limits, as are the other thermal properties of heat capacity, linear expansion, and diffusivity (Table 3-6).

Assumptions and Data Uncertainty. The limited testing on GD-1 core is assumed to be representative of intact rock properties existing at the geologic repository operations area. Uncertainty exists because borehole GD-1 is approximately 5 kilometers (3 miles) from the geologic repository operations area. It may be noted in Table 3-5 that the engineering properties of the clastic rocks sampled in GD-1 vary from low to high strength and from low to high Young's modulus. Thus, it is considered likely that the wide, natural variability of the intact clastic rock media, that might be expected to occur within the site, is already evident in a single borehole. However, the confidence level is expected to increase by statistically meaningful drilling, sampling, and testing at additional locations during site characterization. The more important salt host rock especially needs additional sampling and testing, but, as with the clastic rocks, general characteristics are already evident. Site stratigraphy at the geologic repository operations area is assumed to be as indicated from present exploration. The rock mass properties needed for design have been interpreted from a consideration of the tested, intact rock properties and the rock mass quality inferred from the drilling records for borehole GD-1. While this can be considered a conventional and reasonable basis for the engineering design at this stage of the project, it is not adequate to be considered the final basis for predicting rock mass behavior. Large-scale exploratory excavations and in situ testing to assess rock mass behavior and the significance of larger scale discontinuities, including fracturing and materials anisotropy, will be necessary for this purpose. Additional characterization of in situ stress is also required.

In situ stress measurements have already been made in the salt above, at, and below the proposed repository horizon, and a hydrostatic stress condition equal to lithostatic pressure was inferred from data results (Section 3.2.6.1). The uncertainty, relative to the stress measurements, is that the measurements apply only to salt strata within the Paradox Formation and that the conventional methods of analysis of these measurements may not be entirely appropriate for salt units. There may be stress anisotropy and a maximum in situ stress that is greater than lithostatic pressure in the sedimentary rock overburden above the salt. A high, maximum in situ stress may produce stress concentrations around the shaft excavation that exceed the available strength of the host rock near the shaft wall, where confining pressures are low. This can lead to a disturbed zone of fractured rock surrounding the shaft opening.

Analysis. The static stability of repository excavations into Paradox Salt Cycle 6 is expected to be satisfactory, based on the reported construction performance for the Waste Isolation Pilot Plant (WIPP) (Frobenius et al., 1983). Excavations at WIPP into similar stratigraphy and bedded salt host rock at 700 meters (2,300 feet) have been stable using ordinary mining methods and conventional rock reinforcement techniques. Paradox salt is expected to be more competent than the salt at WIPP, which exhibited continuous clay seam discontinuities within the salt that, in places, required a relatively close roof bolting pattern. The thermomechanical behavior of the rock mass, considering room convergence rates (centerline-roof-to-floor), was also assessed. A practical limit of 10 percent convergence was adopted, after which remedial action (such as scaling the roof) is required to maintain equipment clearance (Russell, 1979, p. 7-10). Calculations show that this limit is not reached 5 years after waste emplacement for an emplacement drift at 850 meters (2,790 feet) (Wagner et al., 1985, BMI/ONWI-512, p. 37). The creep response of salt is temperature-dependent. Therefore, the main haulageways and access drifts, which do not experience as severe a thermal load as the emplacement drifts, will exhibit lower convergence rates.

Due to a lack of empirical data, there is some uncertainty regarding the effect of heat on the deformation of the bedded salt host rock, and how this will affect deformation and room closure rates. While the salt host rock appears to be relatively competent at ambient temperatures, there is a lack of data concerning the effects of heat on the anhydrite and carnallite layers and how this will affect tunnel stability, particularly roof stability. It is expected that tunnels can be kept open by periodic scaling of the roof floor to maintain required clearances, and that excessively difficult repository design and construction procedures will not be required.

6.3.3.2.2 Analysis of Favorable Conditions.

> (1) A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the underground facility.

Evaluation. Based on the Salt Cycle 6 isopachs shown in Figure 3-17, the thickness of Salt Cycle 6 at the site is expected to be between 55 and 65 meters (180 and 215 feet). This permits flexibility in locating the maximum vertical dimension of the repository opening within the host rock. This dimension is nominally 12 meters (40 feet) from the roof of excavation to the base of the canister hole (SCC, 1984, Figure 5-2). Criteria for vertical location of the opening within the host rock horizon were discussed in Section 6.3.1.3.2. Also, based on the wide, uniformly-spread isopach intervals shown in Figure 3-17, it is inferred that there is a considerable degree of flexibility in situating the approximately 8-square-kilometer (3.1-square-mile) subsurface workings.

The evidence indicates that the favorable condition is present.

> (2) A host rock with characteristics that would require minimal or no artificial support for underground openings to ensure safe repository construction, operation, and closure.

Evaluation. Based on examination of cores from GD-1, Salt Cycle 6 appears to be a relatively massive evaporite sequence. Anisotropy within the salt cycle consists of thin

undulatory anhydrite bands (Sections 3.2.3.3 and 3.2.7.1). These anhydrite bands are not considered to be planes of weakness relevant for design purposes because of the 95 to 100 percent rock quality designations (RQDs) (WCC, 1982, ONWI-388, Vol. I, p. 34) calculated for this cycle while drilling GD-1; however, geochemical changes due to increased temperatures will not degrade carnallite "strength" in excess of that expected of salt (Section 5.2.1). Furthermore, the similar creep and "yield" behavior of carnallite suggests that carnallite will have many of the self-healing characteristics of salt. Finally, because of the relatively small amounts of carnallite, distance from repository horizon, and low permeability of salt (Tien et al., 1983, NUREG/CR-3129), it is unlikely that any water released through dehydration of carnallite (which should be minimal for expected temperatures) will have a significant effect on roof support. The effect of the carnallite marker bed, overlying the repository, is not well understood. The effect of heat will be to exacerbate any tendency for roof slabbing to occur. Occasional rock bolting is considered to be the only artificial support that will be required for the underground openings (SCC, 1984, p. 5-6).

There is some uncertainty concerning the effect of heat on the subsurface tunnels and how this will affect reexcavation and support of the tunnels. Room-scale calculations performed by Wagner (1985, ONWI-300) using a viscoelastic constitutive model, indicated that vertical closure along the roof to floor centerline would approach 0.5 meter (1.6 feet) in 5 years for 5.5 by 5.5 meter (18 by 18 foot) rooms in Paradox salt. During this time period, the temperature of the roof will have reached 60 C (140 F) and will not reach a maximum of 95 C (203 F) until 25 years have passed (Wagner et al., 1985, BMI/ONWI-512, Figure 3.2). Hence, rooms and tunnels kept open for more than 5 years will experience larger amounts of closure and will have to be periodically remined or supported to maintain accessibility.

In existing bedded salt mines, openings up to 9.1 meters (30 feet) wide generally stand unsupported. Occasional roof bolts or wire mesh are used to support loose slabs or large spans at mine tunnel intersections. In general, the closure that is measured is due to the slow creep of the salt into the excavation, resulting in heaving of the floor, sagging of the roof, and convergence of the walls. These movements are generally predictable and routinely handled in the mining operation.

The effect of prolonged heating on the failure mechanism of salt tunnels is not well understood because the empirical data base is limited. At Project Salt Vault (Bradshaw and McClain, 1971, ORNL-4555, pp. 210-214), the floor area in Rooms 1 and 4 uplifted very rapidly when the heaters were turned on, but this uplift slowed to a nearly constant rate. Similar behavior occurred when the heat input was increased by 40 percent. When the heaters were turned off, the recovery of the floor uplift amounted to about 16 percent in Room 1 and 11 percent in Room 4, indicating that the mechanism of floor lift was more complicated than simple thermal expansion of salt around the heaters and that creep was the dominant mechanism.

Similar behavior was obtained for deformation of the roof. In addition, gages recorded the behavior of the sagging of a 0.6-meter-(2-foot-) thick bed of salt in the immediate roof of the rooms (Bradshaw and McClain, 1971, ORNL-4555, pp. 219-230). This bed had been identified prior to the start of the experiment and the presence of a thin shale parting 0.6 meter (2 feet) above the ceiling was also recorded. Prior to heating, the rate of sag of this bed was considered normal and harmless. Once the heaters were turned on, however, the acceleration of roof sag immediately increased by a factor of about five. This was unexpected and required remedial action to prevent the development of a hazardous condition. Consequently, the whole experimental area was secured by roof bolting using expanding-shell-bail-type anchors which were 1.2 meters (4 feet) long on 1.2-meter (4-foot) centers.

Convergence measurements made during the Avery Island heater tests (Van Sambeek et al., 1983, ONWI-190[5], Figures 33, 34, and 35) produced roof to floor closures of only 2.54 by 3.1 centimeters (1 by 1.5 inches) after 1,000 days of heating, and no evidence of roof slabbing was reported. These results have little applicability to the present discussion, however, because convergence was measured close to the pillars and not near the center of the rooms, and because domal salt does not contain the stratigraphic weaknesses inherent in bedded salt.

Paradox salt contains thin undulating laminae of anhydrite. Nelson et al. (1982, ONWI-400, p. 82) concluded that the Paradox salt has higher strengths when compared to other salts under similar test conditions and did not note any particular deleterious effects due to the anhydrite layers. These tests, however, were not designed to evaluate roof conditions at elevated temperatures, and no heated field-scale tests have been performed in the Paradox Basin.

It may be concluded that, while thermomechanical calculations can reasonably predict the amount of room closure and far-field behavior due to creep in the salt host rock, they are not reliable in predicting the response of subsurface tunnels in the early stages of heating. There is also little field evidence to indicate what failure mechanisms are acting immediately around the mine openings when bedded salt is heated. It appears, however, that the effect of heating will be to exacerbate any tendencies for slabbing and spalling to occur, but it is not known how serious an effect this may have on tunnel stability and support, mine maintenance costs, and personnel safety. In addition, it is not possible to estimate support requirements for retrieval, which for this evaluation has been considered part of repository operation as defined in 10 CFR 960.2.

The evidence indicates that the favorable condition is not present.

6.3.3.2.3 Analysis of Potentially Adverse Conditions.

(1) A host rock that is suitable for repository construction, operation, and closure, but is so thin or laterally restricted that little flexibility is available for selecting the depth, configuration, or location of an underground facility.

Evaluation. As discussed in Section 6.3.3.2.2, Salt Cycle 6 is approximately 60 meters (200 feet) thick and the estimated thickness of salt required for the repository workings, including allowances for an enveloping disturbed zone, is approximately 30 meters (100 feet) (Section 6.3.1.3.3). Based on this, there is approximately 30 meters (100 feet) of flexibility in locating the repository within the vertical extent of Salt Cycle 6. If the carnallite zone (Section 3.2.7.1) is present in the salt cycle, and if the presence of this hydrous evaporite mineral is found to be deleterious to repository performance, the carnallite zone could limit the flexibility with respect to depth. In general, however, the maximum rock temperature near the canister will be low and transitory, relative to conditions estimated for possible chemical change to carnallite (Section 3.2.7).

As discussed in Section 6.3.3.2.2, there appears to be a considerable degree of flexibility with regard to selecting the configuration and location of a subsurface facility.

The evidence indicates that the potentially adverse condition is not present.

(2) In situ characteristics and conditions that could require engineering measures beyond reasonably available technology in the construction of the shafts and underground facility.

Evaluation. No in situ characteristics or conditions have been identified as requiring engineering measures beyond the state-of-the-art in underground construction (SCC, 1984, pp. 5-1 to 5-16).

During construction of the shafts, penetration of any significant overlying aquifers in the Elephant Canyon, Honaker Trail, and Paradox Formations may require pregrouting or freezing prior to excavation, and will generally require a shaft lining, dewatering pumps, and monitoring systems, which are typical in the mining industry (PB/PB-KBB, 1983, ONWI-496, p. 20). D'Appolonia (1981, ONWI-255) includes an Appendix which is a general review of shaft lining and sealing methods. It presents a detailed discussion of the advantages and disadvantages of freezing, dewatering, and grouting, including suggestions for mitigating adverse consequences, when possible. It also reviews the experience base from sinking shafts through aquifers overlying evaporite deposits, and states that "the Saskatchewan and Boulby examples are of

particular interest in demonstrating that shafts can be sealed to prevent downward seepage into salt deposits, even where relatively high permeabilities and ground-water pressures are involved." The use of ground-freezing technology for shaft sinking is a well understood and viable technique for sinking shafts through well-consolidated or poorly consolidated ground that is partially or fully saturated with water. The process can be applied to soil or rocks that contain pore water or water in fractures. Ground-freezing methods have been used extensively for 100 years, and are considered state-of-the-art technology. The freezing method, which, if required at the Davis Canyon site, appears to have minimal impact on mechanical properties, although clay partings may deform when frozen. If the freezing and thawing cycle results in increased permeability immediately adjacent to the shaft, the potential downward flow can be controlled with installation of a grout curtain or an impermeable keyway below the freeze region.

The salt host rock appears to be relatively competent at ambient temperatures. Construction of underground facilities does not appear to require engineering measures beyond the state-of-the-art in underground construction. However, although no significant findings were made during drilling of GD-1, it is possible that some gas or brine pockets may be encountered during excavation, or that high water inflows could be encountered in penetrating overlying strata. Hazards caused by gas can be mitigated by ventilation monitoring systems, advance probe techniques, elimination of systems that could ignite gases, and if necessary, construction of the facilities following Mine Safety and Health Administration regulation guidelines on safety for gassy mines (30 CFR 57.21). All these measures are reasonably available technologies that are commonly applied in subsurface coal mines.

The evidence indicates that the potentially adverse condition is not present.

(3) Geomechanical properties that could necessitate extensive maintenance of the underground openings during repository operation and closure.

Evaluation. Some reexcavation of passageways and panels is expected to be necessary to maintain excavation geometry due to salt creep and roof slabbing. As discussed in Section 6.3.3.2.2(2), the effect of prolonged heating on the failure mechanism of salt tunnels is poorly understood because of the limited empirical data base. Consequently, it is not known whether salt creep and roof slabbing will have a serious effect on the maintenance costs of subsurface openings during repository operations and closure.

These adverse effects on repository operations can be mitigated to some extent by minimizing the amount of elapsed time between excavation, waste emplacement, and backfilling of the rooms. However, extensive support may be required to maintain the main passageways in the heated host rock that must stay open. In addition, it is not possible to estimate support requirements for retrieval, which for this evaluation, has been considered part of repository operations, as defined in 10 CFR 960.2.

The evidence indicates that the potentially adverse condition is present.

(4) Potential for such phenomena as thermally induced fracturing, the hydration and dehydration of mineral components, or other physical, chemical, or radiation-related phenomena that could lead to safety hazards or difficulty in retrieval during repository operation.

Evaluation. This evaluation assumes that the emplacement rooms will be backfilled after one year. Hence, for retrieval, the re-excavation of the storage rooms and the location of waste canisters is assumed to be required. Geomechanical factors that could also influence waste retrieval in salt are thermal decrepitation of rock adjacent to the canister; creep around, and induced stresses on, the overpack; brine migration toward the canister; and radiation effects on the mechanical behavior of the adjacent rock.

The potential for thermal decrepitation adjacent to the canister is minimal. The maximum design temperature for the canister in salt of 250 C (482 F) (Westinghouse Electric Corp., 1983, ONWI-438, p. 54) was chosen to be below the thermal decrepitation temperature of rock

salt. Moreover, the maximum salt temperature of approximately 250 C (482 F) will occur within less than 0.5 meter (1.6 feet) of the surface of the waste package for a period of less than 20 years, so that, in the worst situation, the effect of increased temperatures would be to disaggregate only a small volume of salt around the waste package. Laboratory testing of Paradox Cycle 6 salt indicates that the actual decrepitation temperature is in excess of 450 C (842 F) (Senseny, 1983, ONWI-9[83-1]), p. 88; Lagedrost and Capps, 1983, BMI/ONWI-522, pp. 58-62). There is no evidence to suggest that likely impurities in the salt in the vicinity of the waste packages would lower the temperature at which thermal decrepitation of the salt occurs to below 250 C (482 F).

Geochemical changes due to increased temperatures will not degrade carnallite "strength" in excess of that expected of salt (Section 5.2.1). Furthermore, the similar creep and "yield" behavior of carnallite suggests that carnallite will have many of the self-healing characteristics of salt. Finally, because of the relatively small amounts of carnallite, distance from repository horizon, and low permeability of salt (Tien et al., 1983, NUREG/CR-3129), it is unlikely that any water released through dehydration of carnallite (which should be minimal for expected temperatures) should reach the waste package and increase corrosion.

Creep of the salt will close the air gap between the canister and the salt host rock shortly after emplacement, resulting in the buildup of stresses on the canister (Wilems et al., 1980, ONWI-203, pp. 48-50). The waste canister overpack is to be designed to resist these lateral stresses resulting from thermal expansion and in situ stresses (Westinghouse Electric Corp., 1983, ONWI-438, p. 54). If retrieval of the waste form after emplacement is required, the creep closure of salt against the canister will require overcoring of the canister, or removal of the waste form from the in-place overpack, both of which will pose some difficulty.

The migration of brine toward the waste canister is a factor in corrosion of the waste overpack. However, the canister will be designed to accommodate this corrosion (Westinghouse Electric Corp., 1983, ONWI-438, pp. 471-479) and remain structurally sound. Analysis in Section 6.4.2.3.3 indicates that corrosion during the period of time for which retrieval may be required (up to 50 years) will not result in waste package failure. However, these same analyses (Section 6.4.2.3.3) indicate that significant amounts of brine could migrate to the vicinity of the waste package during this time interval. Therefore, retrieval operations should not be hampered by corrosion of the canister, but the presence of brine could pose difficulties.

The potential for retrieval problems relating to radiation effects on the mechanical properties of salt is also considered minimal. Based on preliminary studies, the influence of radiation will be limited to the very near-field (within a few meters of the canister), and the radiation effect on mechanical properties is minor (Bradshaw and McClain, 1971, ORNL-4555, pp. 7-10). At the maximum salt design temperature of 250 C (482 F) and at the expected radiation levels, negligible amounts of new brines or chlorine gas will be generated, and they will not pose a threat to workers. Retrieval of the canisters in the presence of radiation could pose additional operational difficulties.

From the preceding discussion, it can be concluded that this potentially adverse condition exists because, although thermal decrepitation of salt adjacent to the waste and radiation effects on salt do not appear to adversely influence waste retrieval, the anticipated requirement to overcome the waste canister, the potential need to remove the waste from the in-place overpack, and the presence of radiation and brine would pose safety hazards and difficulty in retrieval during repository operations. In addition, there is considerable uncertainty regarding the potential effect of the repository thermal load on the stability of openings required for retrieval.

The evidence indicates that the potentially adverse condition is present.

(5) Existing faults, shear zones, pressurized brine pockets, dissolution effects, or other stratigraphic or structural features that could

compromise the safety of repository personnel because of water inflow or construction problems.

Evaluation. Based on present limited data, major shear zones or fault zones are not expected in the host rock at the site. Other structural, stratigraphic, or dissolution features that could compromise the safety of repository personnel have not been identified (Section 3.2).

Brine and gas pockets may be present in the repository horizon. This evaluation does not consider that these features may be identified in advance of the mining operation and precautions taken to minimize the hazard to personnel (Section 6.3.2.2.4).

The evidence indicates that the potentially adverse condition is present.

6.3.3.2.4 Analysis of Disqualifying Condition.

> The site shall be disqualified if the rock characteristics are such that the activities associated with repository construction, operation, or closure are predicted to cause significant risk to the health and safety of personnel, taking into account mitigating measures that use reasonably available technology.

Potential hazards to personnel during repository construction, operation, and closure related to rock characteristics consist of excavation instability, gas pockets, brine pockets, water inflow, and dust. Current data indicate favorable joint and fracture conditions at the repository horizon, but there remains a significant degree of uncertainty regarding the lateral variation that may exist in the site-specific area. Consequently, rock mass behavior relating to preclosure conditions cannot yet be predicted with certainty. However, the design will provide for a range of conditions that might be needed. For example, the extent of joints and fractures in the rock mass will generally dictate the extent of rock reinforcement or support needed to ensure stable excavations. This extent may range from occasional, short rock bolts, to closely spaced, deep rock bolts, or even to rolled-steel roof supports at weak sections or intersections. This scale of increasing support needs is coincident with a scale of increasing time and cost needed to do the work, but represents conventional technology. Similarly, the potential for gas and brine pockets translates to a need for proven mine safety and engineering practices in advancing an excavation heading, such as by doing borehole probing ahead of the face, and by bringing up ample ventilation and dewatering capability behind the face. Current vertical drilling data have not yet exposed any significant evidence of gas and brine pockets, but some uncertainty remains.

These levels of uncertainty will be appreciably diminished by the at-depth testing planned in the exploratory shaft facility described in Section 4.1.2, but the design, nevertheless, will contain provisions of state-of-the-art technology to meet any of the conditions of risk to health and safety discussed.

The evidence does not support a finding that the site is disqualified (Level 1).

6.3.3.2.5 Conclusion for the Qualifying Condition. The site meets all favorable conditions. Three potentially adverse conditions were found to be present. The other two potentially adverse conditions were not found to be present.

However, the analyses and evaluations presented above indicate that it is possible to meet the requirements of the Qualifying Condition.

The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.3.3.3 Hydrology, Guideline 10 CFR 960.5-2-10

The preclosure Technical Guideline on hydrology is concerned with (1) the potential effects of ground water on the construction and sealing of shafts and other underground openings, including the repository itself; (2) the potential for flooding of underground workings by surface water; and (3) the availability of water for repository construction and operation. Its objective is to ensure that the geohydrologic setting will be compatible with repository construction, operation, and closure; will not compromise the functions of shaft liners and seals; and will allow construction, operation, and closure to be achieved with reasonably available technology at reasonable cost.

This guideline includes a qualifying condition, three favorable conditions, and one potentially adverse condition for analysis. It also has one disqualifying condition.

6.3.3.3.1 Statement of Qualifying Condition.

> The site shall be located such that the geohydrologic setting of the site will (1) be compatible with the activities required for repository construction, operation, and closure; (2) not compromise the intended functions of the shaft liners and seals; and (3) permit the requirements specified in Section 960.5-1(a)(3) to be met.

Evaluation Process. To determine whether the Qualifying Condition with respect to hydrology specified in 10 CFR 960.5-2-10 can be met, relevant data are summarized and evaluated. Assumptions and uncertainties are discussed and a brief analysis is provided. Evaluations are made regarding favorable and potentially adverse conditions at the site. These conditions and findings are summarized in a table at the end of Section 6.3.3. Conclusions drawn with respect to qualification of the site for further consideration as a potential repository are presented along with a rationale for these conclusions. Cross referencing is provided to other sections of the report.

Relevant Data. The principal data employed for the evaluation of the site for preclosure hydrology is taken from WCC (1982, ONWI-290, Vol. II; 1982, ONWI-388) which is summarized in Sections 3.3.1 and 3.3.2. Data indicate that the rock units above, below, and within the host rock, in the vicinity of the site, are of generally low permeability, with limited water-production potential. One potentially productive unit, the Elephant Canyon Formation, which is approximately 305 meters (1,000 feet) below ground surface, and 610 meters (2,000 feet) above the repository horizon, has been identified. The surface-water characteristics of the site indicate little runoff, less than 2.5 centimeters (1 inch) per year, and total average precipitation approximately 25 centimeters (10 inches) per year. Local watersheds are small, and summer thunderstorms can cause heavy localized flooding. Flooding potential at the site is described in Section 3.3.1.4.

Assumptions and Data Uncertainties. Primary among the assumptions regarding ground-water conditions at the site is that conditions at the site are similar to those encountered at the GD-1 borehole northeast of the site. This borehole was drilled to a depth of 1,829 meters (over 6,000 feet) and extensively tested. In addition, information from other drillholes in the site vicinity was used to predict site conditions, but none were closer to the site than the GD-1 borehole.

Surface-water data are not site-specific, and analyses are based on information gathered from streams in the candidate area and on the available topographic maps of the area which have a 24-meter (80-foot) contour interval that increases the uncertainty regarding probable maximum flood (PMF) calculations.

It has been assumed that water for use during construction, operation, and closure of the repository can be obtained by purchase or lease of water rights from the Colorado River system. This right to withdrawal would be transferred to the Colorado River south of Moab for withdrawal there, as indicated in Section 5.1.

6.3.3.3.2 Analysis of Favorable Conditions.

(1) Absence of aquifers between the host rock and the land surface.

Evaluation. There is a minor aquifer between the host rock and the land surface. The Elephant Canyon Formation at the GD-1 borehole produced approximately 4 cubic meters per hour (17.6 gallons per minute) of marginal quality water.

The evidence indicates that the favorable condition is not present.

(2) Absence of surface-water systems that could potentially cause flooding of the repository.

Evaluation. Flooding studies of the sites (BGI, 1983, ONWI-476) indicate that there is potential for flooding. This evaluation has not considered that flooding at the site can be mitigated. The probable maximum flood (PMF) floodplain is coincident with part of the site (Section 3.3.1.4; Figure 3-51).

The evidence indicates that the favorable condition is not present.

(3) Availability of the water required for repository construction, operation, and closure.

Evaluation. The San Juan Water Conservancy District indicated willingness to sell up to 3,453,749 cubic meters (2,800 acre feet) of water per year during repository construction, and up to 616,741 cubic meters (500 acre feet) of water per year for operations. Details of water requirements are discussed in Section 5.4.3.5.

The evidence indicates that the favorable condition is present.

6.3.3.3.3 Analysis of Potentially Adverse Condition

Ground-water conditions that could require complex engineering measures that are beyond reasonably available technology for repository construction, operation, and closure.

Evaluation. The geologic section above and within the host rock is composed of low permeability rocks. The Elephant Canyon Formation does yield small quantities of water; however, anticipated inflows to shafts are well within standard engineering practice.

The evidence indicates that the potentially adverse condition is not present.

6.3.3.3.4 Analysis of Disqualifying Condition.

A site shall be disqualified if, based on expected ground-water conditions, it is likely that engineering measures that are beyond reasonably available technology will be required for exploratory-shaft construction or for repository construction, operation, or closure.

Evaluation. The strata above and within the host rock are of generally low permeability. Limited, small flows of ground water would be expected to occur into an open shaft from the strata above the salt; however, control of such small inflows into a shaft under these geologic conditions is well within mitigative capabilities of standard engineering practice.

The evidence does not support a finding that the site is disqualified (Level 1).

6.3.3.3.5 Conclusion for the Qualifying Condition. The surface-water and ground-water systems are compatible with activities required for repository construction, operation, and closure. There is a minor aquifer between the host rock and ground surface; hence, favorable condition (1) is not present. However, estimated inflows to a shaft are well within

mitigative capabilities of standard engineering practice. While it is expected that surface-water systems could cause flooding of the repository, analyses have not considered mitigation of flooding by engineered-design measures. Evaluations to date indicate that water for construction, operation, and closure of the repository would be available from the Colorado River system. The ground-water conditions are considered to be very good for construction, operation, and closure, and the potential adverse condition is not present. The available evidence does not support a finding that the site is disqualified.

The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.3.3.4 Tectonics, Guideline 10 CFR 960.5-2-11

Tectonic processes during the preclosure period could require design features that protect the facilities, the repository workers, and the public. The objective of the preclosure guideline on tectonics is to provide a high degree of confidence that the selected site is not likely to be affected by tectonic events of such magnitude that unreasonable design features would be required.

This guideline includes a qualifying condition, a favorable condition, and three potentially adverse conditions for analysis. It also has a disqualifying condition.

6.3.3.4.1 Statement of Qualifying Condition.

> The site shall be located in a geologic setting in which any projected effects of expected tectonic phenomena or igneous activity on repository construction, operation, or closure will be such that the requirements specified in Section 960.5-1(a)(3) can be met.

Evaluation Process. To determine whether the Qualifying Condition with respect to tectonics specified in 10 CFR 960.5-2-11 can be met, relevant data are summarized and evaluated. Assumptions and uncertainties are discussed and a brief analysis is provided. Evaluations are made regarding favorable and potentially adverse conditions at the site. These conditions and findings are summarized in Table 6-15. Conclusions drawn with respect to qualification of the site for further consideration as a potential repository are presented along with a rationale for these conclusions. Cross referencing to other sections of the report is provided.

Relevant Data. A comprehensive review of published geologic literature has been conducted emphasizing the geologic history of the Paradox Basin, including the entire Colorado Plateau and the surrounding regions of greater geologic activity (WCC, 1982, ONWI-290, Vol. I). These data are reviewed in Section 3.2.5 and are briefly summarized below.

The site lies within the central portion of the Colorado Plateau. The tectonic history of the region was dominated by two major episodes of faulting and folding. The early episode lasted from approximately 310 to 270 million years ago, and the latter one lasted from approximately 70 to 40 million years ago (Section 3.2.5.1). The gentle folds that characterize the candidate area were produced in the latter episode (Section 3.2.5.4). Igneous intrusives (the Abajo and La Sal Mountains) were emplaced approximately 27 million years ago in the vicinity of the site. The closest known area of Quaternary age volcanism lies 127 kilometers (79 miles) east of the site (Figure 3-33 and Section 3.2.5.3).

The most significant late Cenozoic tectonic process has been regional uplift that resulted in the erosion of the deep canyons of the Colorado River system. This uplift has been relatively slow (i.e., probably less than 0.6 meter (2 feet) per 1,000 years for the last 700,000 years) (Section 3.2.5.4).

Geologic mapping of the site vicinity has not indicated the presence of surface faults. Mapping of steep scarps along Shay Graben, south of the site, indicates that this feature may have been reactivated during the Quaternary (Section 3.2.5.1).

Geophysical studies included interpretation of a considerable amount of seismic reflection data for the area. Subsurface faults that may extend upward into the lower part of the Paradox Formation are found in the northeastern and north-central part of the site vicinity (Section 3.2.5.1).

Regional seismologic studies include a review of the historical seismicity of the Colorado Plateau and an evaluation of some of the larger events that have occurred within the Plateau, but outside the Paradox Basin. During the period of the historical seismicity record, 1850 to 1979, no earthquakes are known to have occurred within the site (Section 3.2.5.2). A local network of seismographs capable of recording very small earthquakes has been operating since mid-1979. No earthquakes have been observed within the site. The largest earthquakes observed to date in the Utah portion of the Paradox Basin have been approximately magnitude M_L 3 (Local Magnitude) (Section 3.2.5.2).

The Paradox Basin has been classified as a seismic risk zone 1, relatively low seismic risk (Algermissen, 1969, p. 26) and an area for which the expected peak horizontal ground acceleration is less than a 0.04 gravity with 10 percent probability that the value will be exceeded in 50 years (Algermissen and Perkins, 1976, p. 23). However, these conclusions are based on a historical seismicity record that has limited value by itself. Using the available seismic, geologic, and tectonic data to analyze the possible seismogenic structures within the Paradox Basin (including the Colorado Lineament), a maximum acceleration value can be estimated for the Davis Canyon site. The analysis for the site is conservative by assuming the maximum earthquake can occur on the closest significant geologic structure. Using a peak acceleration relationship for north-central Utah (Campbell, 1982, p. 370), a peak horizontal acceleration of 0.18 gravity is estimated for an M_L 6.5 earthquake occurring on the south Shay Graben fault at a distance of 16 kilometers (10 miles), which is the closest distance to the repository operations area. Other, more distant seismogenic features such as the seismicity cluster along the Colorado River need not be analyzed at this time, because their potential effects are overshadowed by the conservative case adopted. This value may be slightly low for the Paradox Basin because attenuation may be slightly greater in north-central Utah than in the Colorado Plateau. Another relationship, not geographically specific, presented in Donovan (1982), suggests a mean peak value of approximately 0.25 gravity. These estimates indicate the general level of peak accelerations to be expected at the site. Analysis in more detail would be required to specify seismic design criteria.

Continuous temperature logging of borehole GD-1 was performed by WCC during the drilling phase and by the USGS in 1981 and 1982. The two logs collected by the USGS were almost identical, indicating that the well had reached thermal equilibrium (Sass et al., 1983). Using the USGS data for GD-1, the temperature at the repository depth (914 meters [3,000 feet]) in Davis Canyon is estimated to be 34 C (94 F). Thermal gradients determined from GD-1 showed a strong dependence on lithology. For the Elephant Canyon Formation (183 to 381 meters [600 to 1,250 feet]), the temperature gradient was 23.49 C per kilometer (119.54 F per mile); the Honaker Trail Formation (427 to 869 meters [1,401 to 2,851 feet]) was 21.77 C per kilometer (114.56 F per mile); the Paradox Formation (945 to 1,600 meters [3,100 to 5,249 feet]) was 13.04 C per kilometer (89.27 F per mile); and the Leadville Formation (1,798 to 1,922 meters [5,899 feet to 6,306 feet]) was 17.15 C per kilometer (101.17 F per mile) Sass et al., 1983). These results are consistent with the observations by Bodell and Chapman (1982) for the north-central Colorado Plateau, where gradients from 25 drill holes varied between 10 C per kilometer (80.46 F per mile) and 37 C per kilometer (158.67 F per mile), with a mean gradient of 19 C per kilometer (106.53 F per mile). The USGS determined a mean heat-flow value of 66, plus or minus 3 milliwatts per square meter for GD-1. This is consistent with a value of 65 milliwatts per square meter determined for a drillhole north of Shafer Basin southwest of Moab, and an average value of 64 milliwatts per square meter for the area of the salt anticlines near Moab (Bodell and Chapman, 1982).

Assumptions and Data Uncertainties. Deposits younger than approximately 180 million years old are absent from the site (except discontinuous late Quaternary terrestrial deposits), making a detailed interpretation of the Quaternary geologic history of the site difficult using only the stratigraphic record. Therefore, the assumption is made that the site geologic history is similar to that observed in surrounding areas where a more complete

geologic record is available. No structures were discovered in the site or area that were not consistent with the geologic history of the Paradox Basin as derived from regional studies. The geologic setting is taken to be the Paradox Basin, lying within the Colorado Plateau, as shown in Figure 3-3.

The historical seismicity record, which provides some of the basis for earthquake hazard assessment, is limited in several respects. Much of the historical record is incomplete, and some locations of past earthquakes are inaccurate because of the small and sparsely distributed population and inadequate seismographic coverage of the Paradox Basin and Colorado Plateau. The time period of the record is also short relative to geologic time. Because more complete historical records in other regions suggest seismicity can be episodic over long periods, a 130-year record may not be a good representation of the actual long-term seismic potential within the Colorado Plateau.

Microearthquake monitoring of the Paradox Basin indicates that the seismicity has varied spatially and temporally during the past 6 years. Thus, caution must be used in drawing conclusions or extrapolating from the behavior of these small magnitude events.

Some tectonic processes such as broadscale uplift, subsidence, or folding occur at rates that are too slow to affect preclosure activities. The short-term tectonic phenomena that occur on a timescale such that they could affect repository construction, operation, and closure are limited to fault rupture (and any associated uplift or subsidence), earthquakes, and volcanism. If these events have occurred in the Quaternary Period, the evaluation assumes they may recur, and estimates are made of maximum events.

Analysis. All tectonic data available to date indicate that the site is located in a favorable tectonic environment for the construction, operation, and closure of a radioactive waste repository. Seismic risk appears to be low and the threat of volcanic eruptions is virtually nonexistent. The estimated ground motion from a maximum earthquake is higher than design values for most U.S. nuclear power plants (see favorable conditions), but several plants have been built to mitigate against much stronger ground motions. Consequently, no known tectonic hazards exist that require unreasonable mitigation measures during the preclosure phase.

6.3.3.4.2 Analysis of Favorable Condition.

> The nature and rates of faulting, if any, within the geologic setting are such that the magnitude and intensity of the associated seismicity are significantly less than those generally allowable for the construction and operation of nuclear facilities.

Evaluation. This condition considers the relative cost of providing earthquake resistant facilities. In general, structures can be engineered to withstand very high levels of shaking, but costs become unreasonable as design levels increase. A review of design levels for nuclear power plant sites in the United States indicates that about 90 percent have been built for design levels of 0.2 gravity or less. Therefore, the DOE criterion is that a mean-value estimate for peak acceleration of 0.15 gravity, or less, is significantly less than generally allowable. A conservative approach was taken to estimate the mean peak acceleration. In this case the approach assumed the maximum earthquake, M_L 6.5, could occur on Shay Graben, which is the closest significant structure in the geologic setting, the Paradox Basin. The resulting estimate for the mean peak ground acceleration is 0.25 gravity (Section 6.3.1.7.1) This value exceeds the DOE criterion, and the favorable condition is not present. However, 0.25 gravity is moderate compared to design values used for several U.S. nuclear power plants.

The evidence indicates that the favorable condition is not present.

6.3.3.4.3 Analysis of Potentially Adverse Conditions.

(1) Evidence of active faulting within the geologic setting.

Evaluation. Both Shay Graben and the Needles Fault zone (Sections 3.2.5.1) may be found to be "active faults," according to the definition of this term in 10 CFR 960.2. These faults are in the geologic setting.

The evidence indicates that the potentially adverse condition is present.

> (2) Historical earthquakes or past man-induced seismicity that, if either were to recur, could produce ground motion at the site in excess of reasonable design limits.

Evaluation. The largest tectonic earthquake observed to date within the Paradox Basin had a magnitude of about M_L 3. Although not yet firmly established, induced seismicity may be occurring at one location in the Paradox Basin, the Cane Creek mine at Potash. The largest earthquake observed there has been about M_L 3 (Section 3.2.5.2). In either case, an earthquake of this magnitude poses no serious design problems. The expected ground motions at the site from such earthquakes, or even larger, up to M_L 5, are moderate in comparison to design levels for some other nuclear facilities.

The evidence indicates that the potentially adverse condition is not present.

> (3) Evidence, based on correlations of earthquakes with tectonic processes and features (e.g., faults) within the geologic setting, that the magnitude of earthquakes at the site during repository construction, operation, and closure may be larger than predicted from historical seismicity.

Evaluation. Based on the existing seismicity record and current understanding of tectonic character of the Paradox Basin, correlation of earthquakes with tectonic processes or specific faults in the geologic setting are not well defined. Hence for the purposes of this evaluation the presence or absence of young (Quaternary Age) faulting within the geologic setting is used to assess whether or not the frequency of occurrence or magnitude of earthquakes may increase relative to the baseline provided by the historical seismicity record. The condition considers the likelihood that earthquakes during the preclosure period may be larger than those observed historically. Design earthquakes, which are unlikely and very low probability events, are considered under the favorable condition. The historical seismicity record over the past 80 to 100 years is taken as the most likely representation of seismicity over the next 50 years, unless there is contrary evidence for likely events from young faulting in the geologic setting. In general, the observed seismicity in the geologic setting appears to be consistent with the setting's structural and tectonic character. Although there is a possibility that the south Shay Graben fault may be determined to be an active fault and therefore capable of producing an earthquake larger than any historically observed, there is as yet no evidence for Holocene movement on the fault. None of the faults in the geologic setting is known to have moved in the Holocene (the past 10,000 years) (Section 3.2.5.1). Therefore, any movement on these faults in the next 50 years is judged to be unlikely.

The evidence indicates that the potentially adverse condition is not present.

6.3.3.4.4 Analysis of Disqualifying Condition.

> A site shall be disqualified if, based on the expected nature and rates of fault movement or other ground motion, it is likely that engineering measures that are beyond reasonably available technology will be required for exploratory-shaft construction or for repository construction, operation, or closure.

Based on the preceding discussion, three potential sources of ground motion are considered relevant to this analysis:

- Earthquakes occurring in the geologic setting (Paradox Basin) that are not directly associated with individual geologic structures

- Earthquakes that could occur as the result of movement on faults defined as "active faults" in 10 CFR 960.2 (e.g., Shay Graben)

- Seismicity induced by subsurface excavation.

The information presented in Section 6.3.1.7 and analyses in Section 6.3.3.4.3 indicates that ground motion from these potential sources is not expected to be greater than that which can be accommodated by application of available engineering technology.

The evidence does not support a finding that the site is disqualified (Level 1).

6.3.3.4.5 Conclusion for the Qualifying Condition. The favorable condition is not present because the mean-value estimate for peak ground acceleration, 0.25 gravity, is greater than 0.15 gravity which is taken as the value "generally allowable" for construction. However, several United States nuclear facilities have been built for design basis accelerations two or more times greater than the Davis Canyon estimate. One of the three potentially adverse conditions is present. The requirements of the qualifying condition of this guideline are that current tectonic processes or events do not require the development and installation of expensive mitigation measures during construction, operation, and closure of the repository. The condition is met, because seismic hazard in the Paradox Basin is moderate, seismic design is not expected to result in unreasonable construction costs, and there is virtually no threat of igneous or volcanic activity.

The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

Table 6-15 summarizes the evaluations and findings for the preclosure Technical Guidelines requiring site characterization.

6.3.4 Preclosure System Guidelines, 10 CFR 960.5-1(a)(3)

The third preclosure System Guideline is ease and cost of siting, construction, operation, and closure. It is ranked lowest because it does not relate directly to the health, safety, and welfare of the public or the quality of the environment. Here the pertinent elements are (1) the site characteristics that affect siting, construction, operation, and closure; (2) the engineering, materials, and services necessary to conduct these activities; (3) written agreements between the DOE and affected States and affected Indian tribes and the Federal regulations that establish the requirements for these activities; and (4) the repository personnel at the site during siting, construction, operation, or closure.

6.3.4.1 Statement of Qualifying Condition

Preclosure System Guideline 10 CFR 960.5-1(a)(3) defines the specific requirements for Ease and Cost of Siting, Construction, Operation and Closure as follows:

> Repository siting, construction, operation, and closure shall be demonstrated to be technically feasible on the basis of reasonably available technology, and the associated costs shall be demonstrated to be reasonable relative to other available and comparable siting options.

6.3.4.2 Evaluation Process

A complete and detailed evaluation of the preclosure System Guideline will be performed when site characterization has been completed. For this environmental assessment, the available evidence has been used for a preliminary evaluation of the preclosure conditions at the site and the impacts that these conditions have on the ease and cost of repository siting, construction, operation, and closure. The results of this preliminary evaluation are used as the basis for a finding of whether or not the site is likely to meet the qualifying condition.

The siting guidelines list the following technical conditions as being pertinent to meeting the qualifying condition of the preclosure System Guideline:

- Surface characteristics of the site
- Characteristics of the host rock and surrounding strata
- Hydrology
- Tectonics.

For the preclosure System Guideline, an evaluation of these factors focuses on two primary topics:

- Feasibility of the technical aspects of repository siting, construction, operation, and closure

- Reasonableness of the associated costs relative to other comparable siting options.

6.3.4.2.1 Relevant Data. Relevant information with respect to Davis Canyon is discussed under the following:

- Repository conceptual designs (Section 5.1)

- Geologic and hydrologic conditions (Sections 3.2 and 3.3)

- Site characterization activities (Section 4.1.1)

- Exploratory shaft design concepts (Section 4.1.2)

- Assessment of the Technical Guidelines pertinent to this preclosure System Guideline (Section 6.3.3). These are as follows:

  - 960.5-2-8 Surface Characteristics
  - 960.5-2-9 Rock Characteristics
  - 960.5-2-10 Hydrology
  - 960.5-2-11 Tectonics.

6.3.4.2.2 Assumptions and Data Uncertainty. The level of site-specific data presently available has only allowed the iterative engineering process to proceed from a feasibility level to a conceptual level of design. Data from future site characterization activities are required before site-specific designs for the construction, operation, and closure of a nuclear waste repository can be finalized. Data uncertainty relating to site characteristics is discussed as part of the evaluation of the pertinent Technical Guidelines listed in Sections 6.3.4.1 and 6.3.4.2. However, the major assumptions, which are supported by preliminary site information, underlying the engineering work performed thus far, are as follows:

1. Soil and rock conditions are adequate for the building foundations and shaft sinking.

2. Ground-water inflow can be controlled during shaft construction through the use of conventional shaft-sinking techniques.

3. Nongassy subsurface conditions have been assumed during subsurface operations; however, gassy mine conditions can be accommodated through the use of additional design features.

Based on the available site information and design work completed to date, preliminary cost estimates have been developed for the repository described in Chapter 5. These estimates were developed as part of the DOE's annual evaluation of the adequacy of the one mill per kilowatt-hour fee for disposal services and do not represent final cost estimates. More definitive estimates will be completed when more detailed designs and site characterization

data become available. Thus, the evaluation approach of this preclosure System Guideline includes a combination of qualitative and quantitative analyses.

A determination of the applicable Federal, State, and local permit requirements for NWPA repository siting construction, operation, and decommissioning has not been made. Therefore, they have not been specifically considered in the repository cost estimates. The states do not appear to have identical permitting procedures; therefore, the possible cost impact of these permitting procedure differences cannot be quantified. However, the repository concepts, as well as their associated costs, do reflect anticipated design requirements, which will be incorporated into the repository siting, construction, operation, and decommissioning activities in order to comply with the applicable environmental requirements.

6.3.4.3 Analysis

In order to reach a finding on the preclosure System Guideline, an evaluation was made in the context of the group of Technical Guidelines and the available evidence related to the System Guideline. Since the preclosure System Guideline does not have a disqualifying condition, the basis for the evaluation is the likelihood of meeting the qualifying condition for this guideline.

Three of the pertinent Technical Guidelines (Rock Characteristics, Hydrology, and Tectonics) have a disqualifying condition. These disqualifying conditions have been examined in Sections 6.2 and 6.3 and a conclusion was reached that the available evidence did not support a finding that the site was disqualified. In addition, all four of the relevant Technical Guidelines have a qualifying condition. These qualifying conditions have been examined in Sections 6.2 and 6.3 and a conclusion was reached that the available evidence does not support a finding that the site is not likely to meet the qualifying condition. Table 6-16 is a summary of the findings of the Technical Guidelines that are relevant to the preclosure System Guideline. This table includes a summary discussion of the favorable and potentially adverse conditions for the pertinent Technical Guidelines. The results of this table provide a reasonable basis for determining the technical feasibility and reasonableness of the associated costs for repository siting, construction, operation, and decommissioning. The discussion of retrievability in Chapter 5 shows that the retrievability is believed to be reasonably accomplished. A possible retrieval method includes performing the following steps:

- Reexcavation of drifts can be initiated after locating the drifts using in situ markers
- Reexcavation of the drifts. This will require a proof-of-principle demonstration prior to license application
- Locating the waste packages using magnetometers and other detectors
- Overcoring the salt surrounding the waste package with conventional drilling equipment, and removal of the core and salt.

Other methods will be considered prior to selecting a design concept.

Although the System Guideline does not directly address retrievability, it is believed that retrievability is or will be shown to be technically feasible with available technology.

6.3.4.4 Conclusion

Prior repository feasibility designs, together with continuing conceptual design efforts, provide a basis for stating what currently exists in order to design, construct, safely operate, and eventually decommission the structures, systems, equipment, and components, if the nuclear waste repository were to be constructed at this site. In addition, these engineering design efforts have not identified any issues that could prevent repository siting construction, operation, and closure to be in compliance with the applicable Federal, State, and local regulations.

Table 6-16. Preclosure System Guideline Requiring Site Characterization - Ease and Cost of Construction, Operation, and Closure - Davis Canyon Site

System Guideline 960.5-1(a)(3) Ease and Cost of Construction, Operation, and Closure	Associated Technical Guidelines	Assessment Results	Finding
Qualifying Condition:			
Ease and Cost of Construction, Operation, and Closure. The technical aspects of respository construction, operation, and closure shall be demonstrated to be feasible on the basis of reasonably available technology, and the associated costs shall be demonstrated to be reasonable relative to other available and comparable siting options.	Surface Characteristics 960.5-2-8	The Paradox Basin in the general and proposed site area is noted for steep canyons and rugged terrain. The terrain at the surface facility is relatively flat; however, the access road and railroad will be constructed on rugged terrain. These topographical conditions are expected to make the construction of the access road and railroad more expensive and more difficult than for sites with low relief. Because of rugged topography, the site area is well drained. The probable maximum floodplain crosses a portion of the site. Mitigation of floodplain activities has not been fully evaluated. There are no surface-water impoundments whose failures could flood the surface facilities.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
	Rock Characteristics 960.5-2-9	The Davis Canyon site has host rock that is sufficiently thick and laterally extensive for an underground facility. There are no characteristics or conditions of the host rock that will require engineering measures beyond the state-of-the-art in subsurface construction. Occasional rock bolting will be the only artificial support required for the subsurface openings. Periodic scaling will be required to maintain adequate clearances for equipment.	

Table 6-16. Preclosure System Guideline Requiring Site Characterization - Ease and Cost of Construction, Operation, and Closure - Davis Canyon Site
(Page 2 of 3)

System Guideline 960.5-1(a)(3) Ease and Cost of Construction, Operation, and Closure	Associated Technical Guidelines	Assessment Results	Finding
		Salt creep at this site is not expected to pose any unusual hazards to personnel. Some difficulty is expected if the waste canisters must be retrieved after the emplacement rooms are backfilled. Creep closure of salt against the canister will result in the buildup of stresses that will make it difficult to retrieve wastes. Brine pockets may also be present in the host rock, but precautions can be taken to minimize hazards to personnel. Repository construction, operation, and closure are not expected to present hazards that cannot be mitigated by currently available measures or practices.	
	Hydrology 960.5-2-10	The surface-water and groundwater systems are compatible with activities required for repository construction, operation, and closure. The Elephant Canyon Formation is a low-yield aquifer located between the host rock and land surface. Flooding studies indicate that a potential for flooding exists at the site. These conditions are not expected to compromise the functions or safety of the repository, since inflows to shafts are within standard engineering practices and the potential for flooding at the	

Table 6-16. Preclosure System Guideline Requiring Site Characterization - Ease and Cost of Construction, Operation, and Closure - Davis Canyon Site
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System Guideline 960.5-1(a)(3) Ease and cost of Construction, Operation, and Closure	Associated Technical Guidelines	Assessment Results	Finding
		site can be mitigated. Water requirements for repository construction, operation, and closure are expected to be met. Engineering measures that will be required to construct the repository are within currently available technology.	
	Tectonics 960.5-2-11	Current tectonic processes or events do not require the development or installation of unreasonable mitigating measures during repository construction, operation, and closure. Two active fault zones are located within the geologic setting; however, the available evidence indicates that projected levels of seismic activity are within reasonable design limits. No tectonic processes are anticipated that would lead to unacceptable preclosure releases of radionuclides.	

The estimated total life-cycle cost for a repository located in either bedded or dome salt is $8.5 billion (1984 dollars). This includes costs for development and evaluation ($1.8 billion), construction ($1.6 billion), operation ($4.9 billion), and decommissioning ($0.2 billion). The development and evaluation estimate includes costs for site characterization, repository conceptual and license application design, and technology development. The construction estimate includes costs for repository final procurement and construction design and the construction of all surface facilities and a limited number of underground waste disposal rooms and corridors. The operations estimate includes costs for the construction of the remainder of the underground facilities, the emplacement of the waste underground, and caretaker and backfilling activities. The decommissioning estimate includes costs for shaft sealing and the decontamination and dismantling of the surface facilities. These costs are discussed further in Chapter 7.4.

The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.3.5 Conclusion Regarding the Suitability of the Site for Site Characterization

On the basis of the findings stated in the above discussion of individual guidelines and made in accordance with Appendix III of the siting guidelines, it is concluded that the evidence does not support a finding that the site is disqualified, and does not support a finding that the site is not likely to meet the qualifying conditions. Therefore, it is concluded that the Davis Canyon site is suitable for site characterization.

6.4 PERFORMANCE ASSESSMENTS

This section contains preclosure and postclosure modeling assessments in support of other sections of Chapter 6. Contents of this performance assessment section are as follows:

6.4.1 Preclosure Radiological Assessment for Davis Canyon
- 6.4.1.1 Guideline Requirements
- 6.4.1.2 10 CFR Part 20 Calculation
- 6.4.1.3 40 CFR Part 191 Calculation
- 6.4.1.4 Accident Calculations

6.4.2 Preliminary Postclosure Performance Assessment
- 6.4.2.1 Scope and Objective
- 6.4.2.2 Subsystem Descriptions
- 6.4.2.3 Preliminary Subsystem Performance Assessment
- 6.4.2.4 Preliminary System Performance Assessment
- 6.4.2.5 Comparison With Regulatory Criteria
- 6.4.2.6 Effects of Potentially Disruptive Events and Processes
- 6.4.2.7 Conclusions

6.4.1 Preclosure Radiological Assessment for Davis Canyon

The purpose of this section is to provide evaluations of the preclosure offsite radiological conditions which are required for the Davis Canyon Environmental Assessment (EA). Available data are not sufficient to differentiate between the two potential locations in Utah on the basis of existing regulations. Therefore, the following discussion can be applied to either or both Davis or Lavender Canyons. Details of all data, methods, and results are given in Waite et al. (1985, BMI/ONWI-541, Rev. 1). Because of the conservative assumptions made in the analyses, actual repository performance is likely to prove better than documented in this section.

6.4.1.1 Guideline Requirements

The radiological protection requirements pertinent to this discussion are found in 10 CFR Part 60 which defers to 10 CFR Part 20 and 40 CFR Part 191, 10 CFR Part 20 covers both occupational and offsite radiological safety requirements.

Occupational radiation exposure to repository workers has been considered. 10 CFR Part 20 establishes standards which limit the exposure of workers to radiation. The nuclear industry has had experience in maintaining worker doses below these NRC limits. Both engineering controls and radiation protection practices are commonplace in the industry. Also, specific studies on repository worker exposures have been done. These include Kaiser Engineers, 1978; Stearns-Rogers, 1979; DOE, 1980, DOE/EIS-0046F; Bechtel Group, Inc., 1981, ONWI-258, Vols. I-V. All of these studies report that repository worker exposures can be kept below regulatory requirements. Although there is a large data base in this area, a more detailed repository design is needed before a rigorous quantitative evaluation of occupational exposures can be performed. This evaluation will be presented in the Environmental Impact Statement for the repository.

There are two offsite requirements that are applicable. These requirements cover both offsite radionuclide concentrations and doses. The standards that must be satisfied if the NRC is to grant a license are the following:

1. The applicant must demonstrate that the proposed operations are not likely to cause any individual (maximum exposed individual) to receive a dose to the whole body in any period of one calendar year in excess of 0.5 rem (10 CFR Part 20.105[a]).

2. The licensee must not possess, use, or transfer licensed material so as to release to an unrestricted area radioactive material in concentrations that exceed the limits specified in Appendix "B," Table II (Maximum Permissible Concentration Table for Unrestricted Areas) (10 CFR 20.103[a]).

Section 40 CFR 191.03(a) requires that the combined annual dose equivalent to any member of the public (maximum exposed individual) due to operations covered by 40 CFR Part 190 and to direct radiation and planned discharges of radioactive materials covered by this subpart shall not exceed 25 millirem to the whole body, 75 millirem to the thyroid, and 25 millirem to any other organ. 40 CFR 191.03(b) and 191.04 allow for less stringent requirements in some cases. However, the 40 CFR 191.03(a) requirements are more restrictive than these and the 10 CFR Part 20 requirements and are used in these analyses.

In summary, the comparisons required by the guidelines include the 10 CFR Part 20 concentration limits and the 40 CFR Part 191 (maximum exposed individual) dose limits. To lend further insight into the radiological impacts of the presence of a high-level nuclear waste repository at a specific location, the population doses associated with the 40 CFR Part 190 analyses and accident doses have also been included at the end of this discussion. The 10 CFR Part 20 analysis is presented first.

The phases of the repository that are specifically addressed here are construction and operation. The closure phase, the analysis of which is also required by the guidelines, is not addressed explicitly because documentation of all previous decommissioning studies indicates that the radioactive emissions during decommissioning can be controlled to levels far below those during the operational period (BPNL, 1979, DOE/ET-0028, Vols. I - V). For instance, it has been estimated (Smith et al., 1978, NUREG/CR-0130) that during the complete dismantling of a 1,175 megawatt (electric) pressurized water reactor (PWR) only 85 microcuries of radioactive materials would be released to the environment.

Even though there is a difference between a reactor and a repository, the reactor analogy appears to be appropriate in providing a reasonable estimate of the upper bound for potential repository impacts, since release values are expected to be much smaller in the case of the repository. This is partially because there will be less residual mobile contamination at a repository than at a power reactor.

6.4.1.2 10 CFR Part 20 Calculation

According to the requirements of 10 CFR Part 20, the sum of ratios of the individual maximum radionuclide concentrations to maximum permissible concentrations (MPC) in the

unrestricted area must be compared to unity. A result less than one demonstrates compliance. The information required for this calculation includes the following:

- The release rate of each radionuclide
- The atmospheric dispersion characteristics of the site under worst case meteorological conditions
- The point of maximum radionuclide concentration in the unrestricted area.

The radionuclides expected to be released during construction and operation are shown in Tables 6-17 and 6-18, respectively. During the excavation of salt from the repository vault, it is expected that the release of naturally occurring radionuclides contained in the salt will be enhanced. The main radionuclides of interest here are radon (Rn-222) and thoron (Rn-220), and their progeny.

During the routine operation of the repository, releases originating from the disassembly of the spent fuel elements are expected. The disassembly process consists of removing the end fittings and spacers from the assembly so that the individual rods may be placed in canisters in a geometrically efficient manner. Based on a study by the Nuclear Assurance Corporation, (1981), a damage rate for fuel cladding during the disassembly operation has been established. The four radionuclides listed in Table 6-18, H-3, C-14, Kr-85, and I-129, represent the volatile fission gases that will be released in the event of cladding damage. The actual release values were calculated as follows:

1. A damage fraction of 0.005 was established. This is based on the conservative assumption that 1.0 percent of the rods stick within the assembly. It is also assumed that 50 percent of the stuck rods are damaged as they are forced out of the assembly.

2. The number of damaged rods that can be expected in one year is calculated by multiplying the number of rods received per year by the damage fraction. The maximum annual release is calculated based on the maximum number of rods expected in one year. The average annual release is based on an average annual rod receipt rate.

3. The amounts released are determined by multiplying the number of damaged rods, either maximum or average, by the emission from the damage of one rod.

The values listed in Table 6-18 are based only on the receipt of spent fuel as a waste form. While other designs call for the receipt of vitrified waste, the assumption of 100 percent spent fuel as the waste form bounds the release. This is the case since there are no routine operational releases associated with vitrified wastes because of the absence of the volatile radionuclides.

It can be assumed that the emission rate of construction related radionuclides will continue relatively unchanged during the operational period because mining will also continue. Therefore, if only spent fuel is being handled, the total operational release is the sum of the "construction" and "operation" source terms. If only high-level waste is being handled, then the total "operational" release is that represented by the "construction" source terms.

Dispersion values are applied to the radionuclide emission rates to factor in atmospheric dilution, resulting in concentrations of the released material. The maximum concentrations will occur at the point of the maximum X/Q value. For the purposes of this calculation, worst-case meteorology was assumed since these values will yield the greatest concentrations. These assumptions include a Pasquill stability class of F and a wind speed of 1 meter (3.3 feet) per second.

Results were given in Table 6-20. The maximum concentrations occur at 5,000 meters (16,404 feet) from the site. This point is where the maximum sum of concentrations to MPC ratios occurs. The sum at this point is 0.05. Thus, the repository facility combined

Table 6-17. Construction Radionuclide Emissions

Radionuclide	Annual Release Curies	Release Rate Ci/sec
Rn-222	2.9×10^{-4}	9.2×10^{-12}
Po-218	2.9×10^{-4}	9.2×10^{-12}
Pb-214	2.9×10^{-4}	9.2×10^{-12}
Bi-214	2.9×10^{-4}	9.2×10^{-12}
Po-214	2.9×10^{-4}	9.2×10^{-12}
Pb-210	2.9×10^{-4}	9.2×10^{-12}
Bi-210	2.9×10^{-4}	9.2×10^{-12}
Po-210	2.9×10^{-4}	9.2×10^{-12}
Rn-220	2.2×10^{-4}	7.0×10^{-12}
Po-216	2.2×10^{-4}	7.0×10^{-12}
Pb-212	2.2×10^{-4}	7.0×10^{-12}
Bi-212	2.2×10^{-4}	7.0×10^{-12}
Po-212	1.4×10^{-4}	4.4×10^{-12}
Tl-208	7.8×10^{-5}	2.5×10^{-12}

Note: Impacts from these releases do not depend upon the timing of the releases, so no schedule of mining is provided.

Source: Waite et al., 1985, BMI/ONWI-541, Rev. 1.

Table 6-18. Operational Radionuclide Emissions

Radionuclide	Annual Average Release, Curies	Maximum Annual Release, Curies
H-3	$3.2 \times 10^{+1}$	$5.6 \times 10^{+1}$
C-14	2.6×10^{-1}	4.4×10^{-1}
Kr-85	$1.9 \times 10^{+4}$	$3.4 \times 10^{+4}$
I-129	3.2×10^{-2}	5.6×10^{-2}

Source: Waite et al., 1985, BMI/ONWI-541, Rev. 1.

releases during the operational phase are only 5 percent of the NRC limit. This analysis was done only for the operational phase, since the releases during that time would be always greater than during the construction phase. Table 6-19 also shows that krypton-85 is the only radionuclide that contributes significantly to the sum. The radionuclides polonium-218, polonium-214, polonium-216, and polonium-212 were excluded from the calculation because of their short half-lives. They will decay before they reach the unrestricted area.

6.4.1.3 40 CFR Part 191 Calculation

This calculation must be done for all potential exposure pathways (submersion, inhalation, and food chains) at the geographical location which potentially yields the maximum dose available to an individual. An individual at the point of maximum radionuclide concentration is assumed to be the maximum exposed individual.

The radionuclide release rates are the same for this calculation as those shown in Tables 6-17 and 6-18. However, in contrast to the 10 CFR Part 20 calculation, annual average meteorological characteristics were used to calculate the radionuclide concentrations used in dose assessments (Table 6-19).

Anticipating that the micrometeorological characteristics of this site will be important and that the regional nature of the Paradox environmental characterization report (BGI, 1982, ONWI-144) does not adequately reflect these characteristics, the stability for the Paradox was conservatively classified as F with a 1-meter per second (2.24 miles per second) average wind speed. These assumptions result in the least atmospheric dispersion and, therefore, the greatest concentrations. In this atmospheric stability classification system, classification A reflects extremely unstable conditions; B, moderately unstable conditions; C, slightly unstable conditions; D, neutral conditions; E, slightly stable conditions; and F, moderately stable conditions. These data were used to calculate the radionuclide concentrations, and the appropriate dose calculations were made using these concentrations. Site-specific agricultural data (Utah Crop and Livestock Reporting Service, 1978) were used for ingestion calculations; site-independent dose factors were used in the submersion (Kocher, 1983) and inhalation (ICRP, 1982) calculations. Following examination of the doses to individual organs to ensure compliance with applicable regulations, methods recommended by ICRP (1977) were used to combine doses to different organs into the results shown in Table 6-20. Details of this process are to be found in Section 3.2 of Waite et al. (1985, BMI/ONWI-541, Rev. 1).

Although they are not called for in the guidelines, the population doses for the construction and operational phases of the repository are also shown in Table 6-20 because they provide insight into site differences. For these calculations, site-specific demographic data detailed in Waite et al. (1985, BMI/ONWI-541, Rev. 1) were used. The population dose results are shown in units of man-millirem. There are no regulatory limits to which these can be compared. The doses, however, are orders of magnitude below natural background levels.

6.4.1.4 Accident Calculations

Studies of waste handling operations in a repository were performed in conjunction with the preparation of the programmatic Final Environmental Impact Statement (FEIS) (DOE, 1980, DOE/EIS-0046F, Vol. 1, p. 164) (Yook et al., 1984, BMI/ONWI-551) to identify potential accidents in the handling of the waste and to estimate radionuclides that might be released. Based on these studies, with their inherent level of detail from very early designs, it was envisioned that these accidents defined the set of potential scenarios and source terms. Also, every effort has been made to pursue a conservative approach to the analysis of impacts of these selected accidents. Any contention that the analyses are complete must await future improvements in definitions of repository designs and activities. Many of the assumptions and bases for these analyses were taken from Waite et al. (1985, BMI/ONWI-541, Rev. 1). Since the facility design (Section 5.1) being used for impact assessments for this Environmental Assessment (EA) embodies the same basic fuel handling operations, the same accidental events developed for the Generic Environmental Impact Statement (GEIS) were used.

Table 6-19. Comparison of Calculated Radionuclide Emissions with 10 CFR Part 20 Maximum Permissible Concentrations (MPC)

Radionuclide	Emission Rate Ci/Sec	Concentration+ Ci/cm^3	MPC Ci/cm^3	Conc./MPC
Rn-222	9.2×10^{6}	1.8×10^{-15}	3×10^{-9}	6×10^{-7}
Pb-214	9.2×10^{-6}	1.8×10^{-15}	3×10^{-6}	6×10^{-10}
Bi-214	9.2×10^{-6}	1.8×10^{-15}	3×10^{-6}	6×10^{-10}
Pb-210	9.2×10^{-6}	1.8×10^{-15}	4×10^{-12}	5×10^{-4}
Bi-210	9.2×10^{-6}	1.8×10^{-15}	2×10^{-10}	9×10^{-6}
Po-210	9.2×10^{-6}	1.8×10^{-15}	2×10^{-11}	9×10^{-5}
Rn-220	7.0×10^{-6}	1.4×10^{-15}	1×10^{-8}	1×10^{-7}
Pb-212	7.0×10^{-6}	1.4×10^{-15}	6×10^{-10}	2×10^{-6}
Bi-212	7.0×10^{-6}	1.4×10^{-15}	3×10^{-9}	5×10^{-7}
Tl-208	2.5×10^{-6}	5.5×10^{-15}	3×10^{-6}	2×10^{-9}
H-3	1.7	2.2×10^{-11}	2×10^{-7}	1×10^{-4}
C-14	1.4×10^{-2}	1.9×10^{-13}	1×10^{-6}	2×10^{-7}
Kr-85	$1.0 \times 10^{+3}$	1.3×10^{-8}	3×10^{-7}	5×10^{-2}
I-129	1.7×10^{-3}	2.2×10^{-14}	2×10^{-11}	1×10^{-3}
			Total =	5×10^{-2}

Table 6-20. Dose Comparison, Davis Canyon

Construction	
Maximum Exposed Individual	
Annual dose[a]	1.3 mrem
50-year dose commitment	1.2 x 10 mrem
Population	
50-year dose commitment	2.2 x 10^4 man-mrem
Operation	
Maximum Exposed Individual	
Annual dose[a]	1.8 mrem
50-year dose commitment	6.1 x 10 mrem
Population	
50-year dose commitment	2.5 x 10^5 man-mrem

(a) This value represents the annual dose from a one year exposure to the release. This result is the one that should be compared with the 25 mrem whole body dose limit.

Accidents analyzed consist of the following:

I. Shaft Hoist Failure/Spent Fuel (SF).

For this accident, shaft hoist failure is assumed while a waste package is being lowered into the mine for emplacement. Rupture upon impact is postulated with a fractional release of the radioactive content into the ventilation exhaust air stream. The release is assumed to occur over a 1 hour period. The waste package is assumed to hold spent fuel. This release is from ground level.

II. Shaft Hoist Failure/CHLW.

This is the same accidental event as I., but the waste package is assumed to hold commercial high-level waste (CHLW). This release is from ground level.

III. Handling Accident, Receiving Area/SF.

In this accident, a handling mishap is postulated in the receiving area. It is assumed that a cask used for transporting spent fuel to the repository and containing 12 pressurized water reactor (PWR) spent fuel assemblies is crushed by another cask dropped during handling. Release of a fraction of the radioactive inventory in the fuel (gases and particulates) into the receiving area is assumed. This release is from an elevated release point.

IV. Hoist Failure/Remote Handled TRU Waste.

This is the same accidental event as I. and II., except that in this accident four canisters carrying three drums each of remote-handled transuranic waste are dropped down the mine shaft and burst. Twenty percent of the material is assumed to be released from the drums. This release is from ground level.

V. Handling Accident/Operations Area/Contact-Handled TRU Waste.

In this accident, a handling accident is assumed to cause puncture of a drum containing contact-handled transuranic waste. Fractional release of the contents into the operations area is assumed. This release is from an elevated release point.

These accident scenarios are believed to provide bounding conditions, i.e., results in an upper limit to the consequences that might be experienced from waste-handling accidents.

The meteorological conditions assumed were F stability class and 1 meter per second (2.24 miles per hour) wind speed (NRC, 1972; NRC, 1974). This is a conservative approach since it portrays very poor dispersion conditions, thus producing a worst case analysis. The method for the dose assessment is the same as for the routine releases except for one significant change. The exposure from the ingestion of contaminated food is ignored. It is assumed that all foodstuffs grown in the area affected by the accidental release will be collected and examined for signs of contamination. Therefore, this pathway will be cut off. The radionuclide source terms are shown in Tables 6-21 through 6-25 (Waite et al., 1985, BMI/ONWI-541, Rev. 1). The maximum exposed individual is assumed to be at the point of maximum radionuclide concentration in the unrestricted area. For population doses, the assumption is made that the release is into the most populous sector surrounding the release point. The 50-year dose commitment results are shown in Table 6-26. There are no regulatory limits to which these results can be compared.

6.4.2 Preliminary Postclosure Performance Assessment

In this section, a postclosure preliminary performance assessment is made for each of the three major subsystems of the Davis Canyon waste-disposal system: the waste package, the engineered-barrier subsystem, and the geologic subsystem.

Table 6-21. Release from Shaft Drop of CHLW [a]

Radionuclide	Release (Ci)
Y-90	3.9×10^{-4}
Sr-90	3.9×10^{-4}
Ru-106	4.4×10^{-5}
Te-125	4.8×10^{-6}
Cs-134	8.0×10^{-5}
Cs-137	6.0×10^{-4}
Ce-144	2.0×10^{-5}
Eu-154	3.6×10^{-5}
Pu-238	5.6×10^{-7}
Pu-239	1.3×10^{-8}
Pu-240	5.2×10^{-8}
Pu-241	6.4×10^{-6}
Am-241	5.2×10^{-6}
Cm-244	4.4×10^{-5}

(a) The release is assumed to occur over a one-hour time period.

Table 6-22. Release from Shaft Drop of Spent Fuel[a]

Radionuclide	Release (Ci)
H-3	9.
C-14	$6. \times 10^{-2}$
Kr-85	$6. \times 10^{+3}$
Sr-90	$2. \times 10^{-4}$
Y-90	$2. \times 10^{-4}$
I-129	$9. \times 10^{-3}$
Cs-137	2.3×10^{-3}
Pu-238	$6. \times 10^{-6}$
Pu-239	8.7×10^{-7}
Pu-240	1.4×10^{-6}
Pu-241	2.1×10^{-4}
Am-241	4.8×10^{-6}
Cm-244	2.7×10^{-6}

(a) The release is assumed to occur over a one-hour time period.

Table 6-23. Release From Spent Fuel Handling Accident[a]

Radionuclide	Release (Ci)
H-3	5.4
C-14	3.6×10^{-2}
Kr-85	$3.6 \times 10^{+3}$
I-129	5.4×10^{-3}

(a) In this accident, the 12 PWR assemblies in a rail car cask are somewhat crushed in the receiving building by a second cask. Because of filtration, virtually all of the particulate is contained. However, the gases are not totally filtered. It is assumed that 30 percent of the void gases in the pins would be released by the accident.

Table 6-24. Release From Shaft Drop of Remote-Handled TRU Accident[a]

Radionuclide	Release (Ci)
H-3	2.5×10^{-1}
C-14	4.4×10^{-4}
Mn-54	8.1×10^{-8}
Co-60	1.6×10^{-6}
Ni-63	1.6×10^{-7}
Sr-90	1.2×10^{-8}
Nb-95	8.2×10^{-8}
Cs-137	1.9×10^{-8}
Pu-238	1.1×10^{-9}
Pu-239	7.2×10^{-11}
Pu-240	1.5×10^{-10}
Pu-241	3.6×10^{-8}
Am-241	1.4×10^{-10}
Cm-242	2.0×10^{-9}
Cm-244	1.4×10^{-9}

(a) The only credible accidents that happen with the remote-handled TRU (some 34,365 drums) are bounded in consequences by the shaft drop. In this accident, four canisters carrying three drums each are assumed to be dropped into the mine shaft and burst. Some 20 percent of the material is assumed to be released from the drums.

Table 6-25. Release From Contact-Handled TRU Puncture Accident[a]

Radionuclide	Release (Ci)
H-3	6.3×10^{-6}
C-14	1.6×10^{-10}
Co-60	6.2×10^{-13}
Sr-90	$9.2 \times c10^{-13}$
Nb-95	1.1×10^{-11}
Ru-106	2.8×10^{-10}
I-129	1.6×10^{-4}
Cs-134	1.8×10^{-12}
Cs-137	1.4×10^{-12}
Pu-238	8.2×10^{-12}
Pu-239	5.4×10^{-13}
Pu-240	1.1×10^{-12}
Pu-241	2.7×10^{-10}

(a) The most credible accident that can happen to contact-handled TRU is the puncture of the drum and subsequent release of the drum's contents.

Table 6-26. Accident Dose Comparison, Davis Canyon

I.	Accident Spent Fuel Drop	50-Year Dose Commitment
	Maximum Exposed Individual	$4.68 \times 10^{+1}$ mrem
	Population	$1.64 \times 10^{+2}$ man-mrem
II.	CHLW Drop	
	Maximum Exposed Individual	2.74 mrem
	Population	9.63 man-mrem
III.	Remote-Handled TRU Drop	
	Maximum Exposed Individual	3.10×10^{-3} mrem
	Population	1.09×10^{-2} man-mrem
IV.	Spent Fuel Handling	
	Maximum Exposed Individual	3.98×10^{-2} mrem
	Population	$6.61 \times 10^{+1}$ man-mrem
V.	Contact-Handled TRU Puncture	
	Maximum Exposed Individual	2.07×10^{-9} mrem
	Population	3.44×10^{-6} man-mrem

6.4.2.1 Scope and Objective

The evaluation of the proposed Davis Canyon site with respect to 10 CFR Part 960, Subparts C and D, provides part of the basis for site nomination. The guidelines specify that the evaluation be made using preliminary performance assessments to estimate the likelihood of satisfying regulatory performance criteria contained in the NRC 10 CFR Part 60 regulation and the EPA 40 CFR Part 191. A preliminary performance assessment of the Davis Canyon site is presented in this section, and results of the assessment are used in Section 6.3.2, postclosure System Guideline, as part of the evaluation of the site.

Because of current limitations on the data base and analytical methods, this preliminary assessment is not intended to demonstrate satisfaction of the postclosure System Guideline; rather, it is intended to supplement the evidence that will be used to establish whether the Davis Canyon site is suitable for site characterization. A full performance assessment that will be used to demonstrate satisfaction of the postclosure System Guideline is contingent upon and will follow site characterization.

Section 6.4.2 is organized into various subsections. Section 6.4.2.2 contains descriptions of the three major subsystems of the proposed Davis Canyon waste-disposal system: the waste package, the engineered barrier subsystem, and the geologic subsystem. The individual performance of each of these major subsystems is evaluated in Section 6.4.2.3. The specific objectives of these evaluations are (1) to satisfy the need for preliminary performance assessment of subsystems as specified in Subpart B of 10 CFR Part 960, and (2) to establish the reference case system configuration to be used in the analysis of Section 6.4.2.4. Section 6.4.2.4 contains a preliminary assessment of total system performance. In Section 6.4.2.5, subsystem and total system performance discussed in earlier sections are evaluated in terms of the applicable performance objectives of 10 CFR Part 60 and 40 CFR Part 191. The objective of these evaluations is to establish a rough measure of undisturbed-system performance that can be used as evidence in the overall site evaluation. A brief discussion of system performance under disturbed conditions such as human intrusion and disruptive events is provided in Section 6.4.2.6. Conclusions are summarized in Section 6.4.2.7.

6.4.2.1.1 Code Status. The status of various individual codes planned for performance assessments for licensing is described in the performance assessment plan (ONWI, 1984, BMI/ONWI-545). Codes used for preliminary performance assessments for the statutory environmental assessment described here are (1) a radionuclide inventory and source term code, ORIGEN-2; (2) a time-dependent thermal analysis code, TEMPV5; (3) a brine migration code, BRINEMIG; (4) a nuclear radiation shielding analysis code, ANISN-W; and (5) a waste package performance analysis code, WAPPA. The status of documentation, verification, and validation activities is variable for these codes and their use here does not suggest their use in future performance assessments. The status of all except TEMPV5 is given in the performance assessment plan. TEMPV5 is a modified version of TEMP which is described in the performance assessment plan. The major change of TEMP that was included in the TEMPV5 modification was to analytically include the important fact that the thermal conductivity of salt decreases with increasing temperatures. Additional details about each code are given in the appropriate following sections.

6.4.2.2 Subsystem Descriptions

For the purpose of these assessments, it is assumed that a repository at Davis Canyon would be constructed in the Paradox Formation, a 762- to 914-meter (2,500- to 3,000-foot) thick sequence of interbedded salt, anhydrite, shale, dolomite, and limestone. The repository would be located entirely within Cycle 6, a salt bed approximately 61 meters (200 feet) thick. The subsurface working areas of approximately 781 hectares (1,930 acres) would be located about 914 meters (3,000 feet) from the surface (Figure 5-6 and Table 5-1). Mined areas would occupy no more than 30 percent of the subsurface working areas. For this preliminary performance assessment, it is assumed that the waste inventory will be 10-year-old spent fuel (SF) or commercial high-level waste (CHLW) after a burnup of 32,717 MWD per ton with intermittent shutdowns representing 72,000 metric tons (79,366 tons) of heavy metal. The first

repository, as specified in the Nuclear Waste Policy Act (NWPA) of 1982 (42 USC Sections 10101-10226), can contain up to 70,000 metric tons of heavy metal (MTHM) (77,110 tons) until a second repository becomes available. The 72,000 MTHM (79,366 tons) used in this repository concept is conservatively high with respect to the NWPA interim limit for the first repository. The repository concept described in Chapter 5 included approximately 36,000 metric tons (39,683 tons) of each and quantities of transuranic (TRU) and defense high-level wastes (DHLW). TRU and DHLW wastes do not generate significant quantities of heat and will be emplaced in zones that do not have significant increase in temperature caused by dissipation of the heat from high-level wastes. Thus, preliminary performance assessments of CHLW and SF may be performed independent of the presence of these other wastes. Performance assessments accompanying site characterization will include DHLW and TRU. Performance assessments are performed for each of the SF and CHLW which bracket the expected performance of the repository concept, i.e., Case I with 100 percent SF; Case II with 100 percent CHLW. Radionuclide inventory compositions obtained from ORIGEN-2 (Croff, 1980, ORNL-5621) computer runs for SF from pressurized water reactors and CHLW are listed in Table 6-27.

Functionally, the waste-disposal system is made up of three major subsystems: (1) the waste package; (2) the mined repository, including additional engineered barriers, if any; and (3) the geologic, including geohydrologic and geochemical setting of the site. Those parts of each of the three subsystems relevant to postclosure systems performance are described below.

6.4.2.2.1 Waste Package Subsystem. The waste package configuration that was analyzed is the borehole emplacement concept shown in Figure 6-4 which was designated Alternate II by Westinghouse Electric Corp. (1983, ONWI-438, pp. 14, 16). Because the waste package design is continuing, the final design is not available, but results should be typical of what can be achieved. The 52-centimeter-diameter, 3.7-meter-long (21-inch-diameter, 12-foot-long) spent fuel waste form is made up of close-packed, disassembled, pressurized-water reactor fuel pins (SFPWR) from 10 pressurized water reactor (PWR) assemblies 4.614 metric tons (5.086 tons) of heavy metal in a thin-walled canister. There will also be SF from boiling-water reactors (SFBWR) which will be emplaced in a repository. Radionuclide inventory differences per unit weight of spent fuel (SF) are insignificant for the purposes of this report. This analysis will consider only the SFPWR, which, when loaded in the Alternate II package design, generates more heat per package than SFBWR. Thus, the analysis is conservative. The commercial high-level waste form (CHLW) is 76-68 borosilicate glass containing (Westsik et al., 1983, PNL-3172, p. 5) reprocessed waste from 9.65 metric tons (10.63 tons) of heavy metal of nuclear fuel. The SFPWR canister is surrounded by a 12-centimeter-thick (4.72-inch-thick) container wall of low-carbon steel. The CHLW package has a 15-centimeter-thick (5.9-inch-thick) container wall of the same material. The borehole is backfilled with about 2 centimeters (.78 inch) of crushed salt around the package and up to the floor. The waste is assumed to be emplaced 10 years after the fuel is discharged from the reactor, with the CHLW package initially generating 9.5 kilowatts of heat and the SFPWR package generating 5.5 kilowatts (Jansen, 1985). The waste-package dimensions are given in Table 6-28. As corrosion proceeds, oxide corrosion products accumulate in the space previously occupied by the steel overpack. This process is described in more detail in Section 6.4.2.3. The canister is expected to last only a few years after failure of the overpack. This analysis ignores containment that would be provided by the canister.

6.4.2.2.2 Engineered Barrier Subsystem. The guidelines define the engineered-barrier system as "the manmade components of a disposal system designed to prevent the release of radionuclides from the underground facility or into the geohydrologic setting. . . [which] includes the radioactive waste from 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." At this time, the engineered barrier means the waste package in the discussion of repositories in salt. Any containment or sorption effects provided by the crushed-salt backfill in repository rooms (and around the waste packages) are ignored for the purpose of this performance assessment. General descriptive information about the repository concept is given in the following paragraphs. Refer to Chapter 5 for more details.

Table 6-27. Radionuclide Inventories[a] in 72,000 MTHM of SFPWR and the Equivalent of 72,000 MTHM of CHLW at Various Times After Emplacement

Nuclide	Half-Life, yr	Inventory, Ci 0 yr CHLW	0 yr SFPWR	200 yr CHLW	200 yr SFPWR	1,000 yr CHLW	1,000 yr SFPWR
C-14	5,730	111,000	111,000[c]	108,000	108,000[c]	98,000[c]	98,000
Se-79	65,000	29,200	29,200	29,100	29,100	28,900	28,900
Sr-90	28.9	4.09E + 9[b]	4.09E + 9	3.50E + 7	3.50E + 7	0.188	0.188
Tc-99	213,000	933,000	934,000	932,000	933,000	930,000	931,000
Sn-126	100,000	55,300	55,300	55,200	55,300	54,900	55,000
I-129	1.60E + 7	2,250[c]	2,250	2,250[c]	2,250	2,250[c]	2,250
Cs-135	2.30E + 6	24,200	24,200	24,200	24,200	24,200	24,200
Cs-137	30.2	5.87E + 9	5.87E + 9	5.77E + 7	5.78E + 7	0.542	0.542
Th-232	1.40E+10	1.07E-5	1.07E-5	1.16E-5	1.93E-4	1.53E-5	9.43E-4
U-233	159,000	0.00976	1.96	22.7	28.5	152	232
U-235	7.04E+8	6.29	1,260	6.31	1,260	6.42	1,280
U-236	2.34E+7	91.9	18,400	94.3	18,600	104	19,500
U-238	4.47E + 9	114	22,900	114	22,900	114	22,900
Np-237	2.14E + 6	22,400	22,400	29,100	38,400	42,000	71,400
Pu-238	87.7	8.16E + 5	1.63E + 8	354,000	3.38E + 7	9,860	70,500
Pu-239	24,100	113,000	2.25E + 7	120,000	2.24E + 7	143,000	2.19E + 7
Pu-240	6,540	188,000	3.77E + 7	431,000	3.72E + 7	396,000	3.41E + 7
Pu-241	14.7	2.77E + 7	5.54E + 9	11,700	375,000	9,240	9,240
Pu-242	376,000	609	122,000	629	122,000	643	122,000
Am-241	432	1.21E + 8	1.21E + 8	8.83E + 7	2.26E + 8	2.45E + 7	6.27E + 7
Am-243	7,380	1.19E + 6	1.19E + 6	1.17E + 6	1.17E + 6	1.08E + 6	1.08E + 6
Cm-244	18.1	9.07E + 7	9.08E + 7	43,000	43,000	2.16E-9	2.17E-9
Cm-245	8,500	10,000	10,000	9,850	9,850	9,220	9,230

Note: Apparent discrepancies may appear because of rounding to 3 significant figures.

(a) ORIGEN-2 computer runs made for SRPO data base - 32,717 megawatt days per metric ton burnup with intermittent shut downs (Jansen, 1985).

(b) 4.09E + 9 = 4,090,000,000.

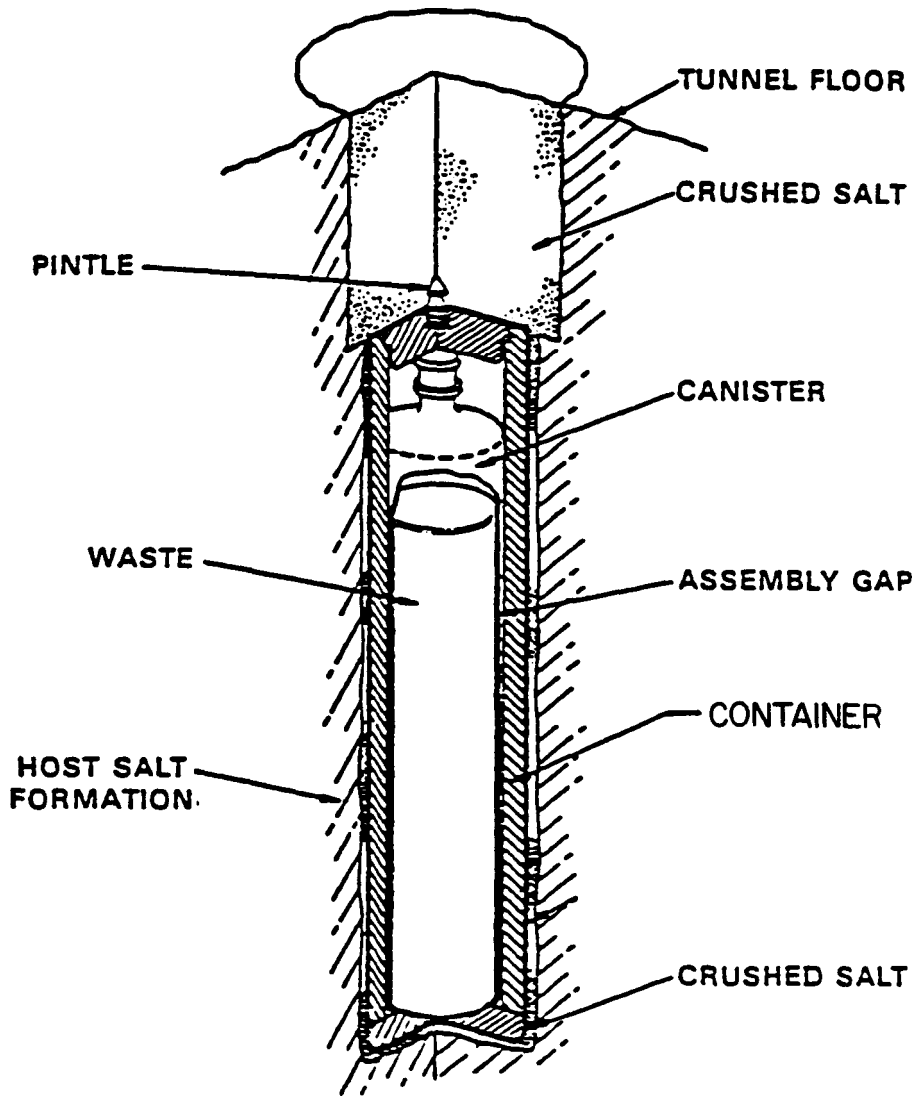
(c) This element is not in the CHLW inventory. It would be separated in the fuel reprocessing plant and stored separately.

Table 6-28. Uncorroded Waste Package Cross-Section Dimensions

Material	Inner Radius, cm	Wall Thickness, cm	Outer Radius, cm	Diameter	
				Inner, cm	Outer, cm
CHLW Borehole Concept Reference Package (ONWI-438, Table 1.2, page 14, designated Alternate II)					
Waste	0.00	26.73	26.73	0.00	53.46
Canister[a]	26.73	1.27	28.00	53.46	56.00
Oxide	28.00	0.00	28.00	56.00	56.00
Air Gap	28.00	1.50	29.50	56.00	59.00
Container[b]	29.50	15.00	44.50	59.00	89.00
Oxide	44.50	0.00	44.50	89.00	89.00
Crushed Salt	44.50	2.50	47.00	89.00	94.00
SFPWR Borehole Concept Reference Package (ONWI-438, Table 1.3, page 16, designated Alternate II)					
Waste	0.00	27.86	27.86	0.00	55.73
Canister[a]	27.86	0.64	28.50	55.73	57.00
Oxide	28.50	0.00	28.50	57.00	57.00
Air Gap	28.50	1.25	29.75	57.00	59.50
Container[b]	29.75	12.00	41.75	59.50	83.50
Oxide	41.75	0.00	41.75	83.50	83.50
Crushed Salt	41.75	2.75	44.50	83.50	89.00

(a) 316 stainless steel.
(b) Low-carbon steel.

Source: Westinghouse Electric Corp., 1983, ONWI-438.



Configuration of Emplaced Waste Package

Source: Jansen, 1985

Figure 6-4

Waste packages are to be emplaced in single rows in the floor of each storage room as shown by Figure 6-5. Repository areal loadings at the time of emplacement of 15 and 30 watts per square meter for spent fuel and CHLW respectively were chosen. These areal loadings do not include areas associated with shafts, TRU rooms, etc. The area associated with each package is the area defined by the intersections of lines drawn midway between packages parallel to, and perpendicular to, the storage tunnels, which is equal in area to $S \times P_L$ (Table 6-29). Tunnels are to be backfilled with crushed salt.

For the purpose of this preliminary performance assessment, the engineered-barrier subsystem boundary is the outside surface of each overpack of each waste package. Hypothetical nuclide releases from the engineered-barrier subsystem to the geologic subsystem are assumed to commence at the time of overpack failure and are assumed to be limited only by the quantity of each nuclide that would dissolve into the quantity of brine available (ignoring the consumption of brine by chemical reaction with the overpack). Further details are given in Section 6.4.2.3.

6.4.2.2.3 Geologic Subsystem. The geological subsystem consists of three hydrostratigraphic units (HSU):

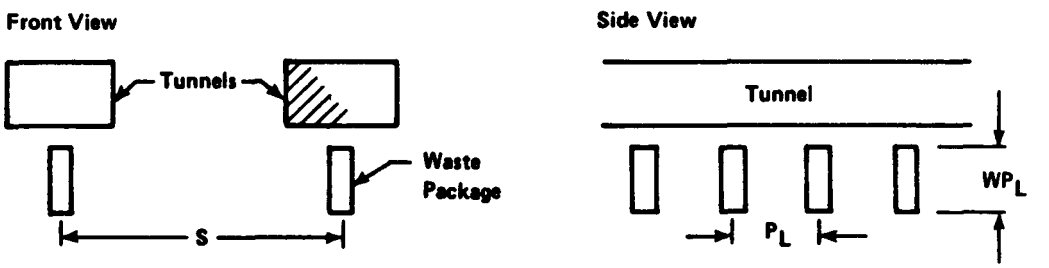
1. Upper HSU is a freshwater aquifer system about 610 meters (2,000 feet) thick, of Permian age sedimentary bedrock (shale, sandstone, limestone).

2. Middle HSU, the Paradox Formation, is a 762- to 914-meter (2,500- to 3,000-foot) thick sequence of evaporite and carbonate bedrock, with more than 50 percent halite.

3. Lower HSU is a Permian age, sedimentary bedrock (limestone, siltstone, sandstone), aquifer system approximately 152 to 305 meters (500 to 1,000 feet) thick. Ground water in the Lower HSU is under artesian pressure, and contains total dissolved solids ranging in concentration from less than 10,000 parts per million to more than 325,000 parts per million.

In the middle Gibson Dome area, the head in the Upper HSU is generally higher than the Lower HSU by as much as several hundred feet. The head in the Middle HSU of Gibson Dome Test Well No. 1 was 750 meters (2,460 feet) above mean sea level, which is several thousand feet lower than the head at the Upper and Lower HSUs at this location. Abnormally high pressures in the Middle HSU have been encountered at salt anticlines and other scattered sites in the study area. The host rock for the proposed repository is in the Middle HSU, Salt Cycle 6, a 61-meter (200-foot) thick salt bed at a depth of 914 meters (3,000 feet) below the ground surface. The repository is separated from the Upper HSU, including the Elephant Canyon Formation (a fresh-water aquifer), and the Lower HSU, including the Leadville Limestone (a deep brine aquifer), by interbedded salt, shale, limestone, and dolomite. Ground-water movement through the bedrock in the study area is through primary and secondary openings in the bedrock. See Chapters 3 and 5 for more details.

The expected performance of the geologic subsystem for a salt repository is approximated by considerations of (1) the migration of brine toward the heat sources provided by the waste packages, (2) the possible mobility of brine by diffusion away from waste packages after package failure with dissolved radionuclides, and (3) the flow of ground water toward the accessible environment with dissolved radionuclides if radioactivity has been encountered by the ground water for any reason. Sorption of radionuclides by salt is considered to be low and is ignored for this performance assessment. Sorption to varying degrees would occur in the ground-water system and will be considered in those cases, if any, where radioactivity has been encountered by ground water. The extent of the disturbed zone and its impact on water travel times will be estimated. The contamination of major sources of ground water by radioactivity will be estimated, as required by 40 CFR Part 191. Additional details concerning the processes and phenomena that impact radionuclide transport are given in Section 6.4.2.3. Additional details concerning the characteristics of the geologic subsystem are given in Chapter 3.



Repository High-Level Waste
Storage Placement

Figure 6-5

Table 6-29. Repository High-Level Waste Storage Parameters

Waste[a] Form	Area Loading[b] W/M^2	Waste Packages[b] per Room	Number[b] of Waste Packages	Overpack[a] Outer Diameter[c]	$P_L(b,c)$	$S^{(b,c)}$	$WP_L(a,c)$
SFPWR	15	9	7,899	0.835	18.3	20.1	3.85
CHLW	30	13	3,673	0.890	12.2	26.2	3.68

(a) Westinghouse Electric Corp., 1983, ONWI-438.
(b) McNulty, 1985.
(c) Dimensions in meters (m).

6.4.2.3 Preliminary Subsystem Performance Assessment

Analyses have assessed the expected performance of the engineered and natural barriers in a nuclear waste repository in Davis Canyon. When possible, results of these analyses have been compared to the NRC regulation and the EPA standards. These analyses have considered both commercial high-level waste (CHLW) and spent fuel from pressurized water reactors (SFPWR).

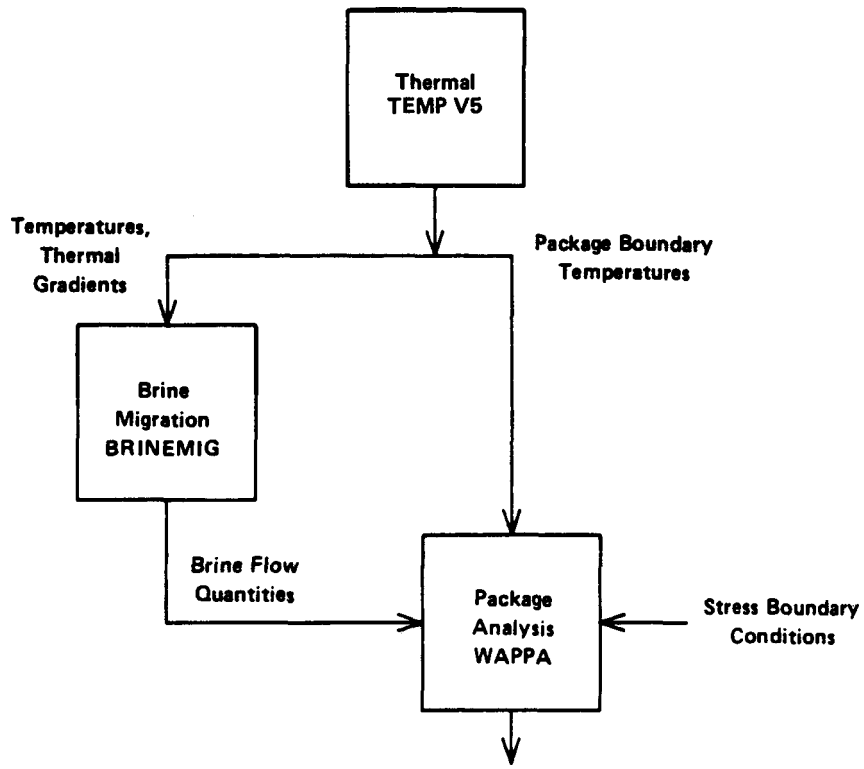
Consideration of several interacting phenomena are required to assess the expected performance of an engineered-barrier system in salt. These interactions are schematically depicted by Figure 6-6, which also indicates the specific codes that are used for the analyses discussed in this section. The WAPPA code (INTERA, 1983, ONWI-452) analyzes the interactions of several phenomena in addition to those shown in Figure 6-6. Figure 6-6 shows that package boundary temperatures are calculated by TEMPV5 (McNulty, 1985); a thermal code, and brine flow rates are estimated using BRINEMIG (McCauley and Raines, 1985). These data are used for calculation of corrosion and the other phenomena embodied in WAPPA. Package failure times and radionuclide source concentrations as calculated by WAPPA are compared with the NRC regulations given in 10 CFR Part 60 and 40 CFR Part 191 standards for release to the accessible environment. If releases from the package are below 40 CFR Part 191 standards, then releases to the accessible environment are clearly below the standard. Radionuclide source concentrations are also made available for radionuclide transport calculations, if needed. These preliminary analyses apply to a typical package located several packages away from the edge of the repository. Packages near the edge of a repository are subject to lower temperatures and smaller brine flow quantities and, consequently, should normally have longer life and lower releases of radionuclides.

Section 6.4.2.3.1 discusses thermal conditions that the Davis Canyon repository will sustain after the emplacement of nuclear waste. Major factors that affect temperature levels, in addition to the waste package loading and spacing, are in situ temperature and thermal conductivity of the salt host rock. Section 6.4.2.3.2 shows that the in situ moisture content of bedded salt and thermal gradients and temperatures around a waste package lead to a small amount of brine migrating toward each waste package.

Preliminary corrosion performance assessments in Section 6.4.2.3.3 show that the waste package is expected to last for longer than 10,000 years. However, even if an unexpected breaching of the waste package were to occur, Chambre et al. (1982) have found that the low solubility of container and overpack materials, such as iron, and of most nuclides, in addition to factors such as stagnant liquid films, and accumulated corrosion layers remaining in space previously occupied by the metal in the waste package, will limit the nuclide release rate from the waste form. These factors, other than nuclide solubility, as discussed in the next paragraph, are not considered by this analysis. Hence, these factors add to the conservatism of the calculations. These factors will be the subject of study during site characterization.

Since no specific engineered barriers beyond the waste package are included in this preliminary analysis, releases from the waste package subsystem are compared to the 10 CFR Part 60 requirements. Hypothetical nuclide releases are assumed between 300 and 10,000 years. The releases are conservatively large because of the omission of consideration of the factors discussed in the previous paragraphs, and are assumed to be limited only by the quantity of each nuclide that would dissolve into the quantity of brine available (Section 6.4.2.3.2). These calculations are described in Section 6.4.2.3.4. Additional data concerning solubilities will be obtained during site characterization.

Ground-water flow will be discussed in Section 6.4.2.3.5, regarding seal performance. An estimate of the extent of the disturbed zone, possible flow through host rock, and flow in aquifers will be included in the discussion. Ground-water travel time will be compared with 10 CFR Part 60 requirements. Additional data concerning ground-water flow will be obtained during site characterization.



System Analyses for Assessment of Performance of Engineered Barriers

Figure 6-6

6.4.2.3.1 Thermal Conditions. Preliminary thermal analyses using estimated thermal properties and geothermal gradients for the Davis site provide time-dependent boundary temperatures for the waste package assessments in Sections 6.4.2.3.3 and 6.4.2.3.4, and radial profiles of temperature for the brine-migration calculations in Section 6.4.2.3.2. Section 6.4.2.3.3 shows that temperatures have less impact on waste package performance than the in situ moisture content of salt. Table 6-30 and Figure 6-1 show that maximum expected surface temperatures on the waste package will reach 236 C (457 F) for commercial high-level waste (CHLW) and 134 C (273 F) for spent fuel from a pressurized water reactor (SFPWR). This section discusses the analytical approach, data base, and uncertainty and results of the thermal analyses.

Analytical Approach. McNulty (1985) used the TEMPV5 code to estimate time-dependent temperatures around the waste package. The TEMPV5 code uses an analytical solution of finite line sources in an isotropic and infinite-medium to model individual waste packages. Site-specific conditions may vary from the assumptions. The code uses linear superposition of temperature contributions from individual finite line sources as described by an analytical integration to calculate the temperature at a point. The TEMPV5 code allows either simultaneous emplacement of all waste as an infinite array of canisters, or sequential emplacement of waste into various regions of the repository. This analysis assumes simultaneous emplacement in an infinite array. McNulty found that sequential emplacement has little effect on waste package surface temperatures. A transformation technique accounts for the dependence of thermal conductivity on temperature. TEMPV5 does not assume a homogeneous medium (a medium whose properties are constant throughout), because it allows thermal conductivity to vary with temperature throughout the infinite medium; however, TEMPV5 cannot model a layered medium. The transformation does not account for the temperature dependence of diffusivity. However, McNulty shows that the temperature dependence of diffusivity has a small effect on computed temperatures.

Data Base and Uncertainties. The data used in the analyses consisted of thermal properties (Lagedrost and Capps, 1983, BMI/ONWI-522, Tables 3, 4, 5), waste-package parameters (Westinghouse Electric Corp., 1983, ONWI-438, Tables 1-2 and 1-3), and baseline repository inventory and design parameters (SCC, 1984). Uncertainty exists in thermal conductivities and ambient in situ temperatures. Duffey (1980, SAND79-7050, pp. 3-7 and 59) and Wagner (1985, ONWI-300, p. 9) have observed lower thermal conductivities in the laboratory than in the field. Sampling disturbance of the kind reported by Lagedrost and Capps (1983, BMI/ONWI-522, p. 14) can reduce thermal conductivities measured in the laboratory. Consequently, Loken et al. (1984, Figure D-3) have suggested an increase of 40 percent in laboratory thermal conductivities as a correction. The analyses used ambient in situ temperature of 33.7 C (93 F). McNulty (1985) presents more details on the use of these and other data.

Thermal Analyses And Results. Separate thermal analyses were made for CHLW and SFPWR wastes. The calculations of McNulty (1985) used an infinite array configuration for the layout of the waste packages. Figure 6-1 shows the time-dependent variation of temperature at the surface of the CHLW and SFPWR waste packages. Table 6-30 summarizes temperatures for both wastes as a function of time. These analyses predict that expected maximum temperatures on the surface of a waste package would reach 236 C (457 F) for CHLW at 5 years and 134 C (273 F) for SFPWR waste at 10 years. The temperatures reflect the combined effect of site-specific thermal conductivities and ambient in situ temperature. Uncertainty exists in the expected thermal conditions. However, waste-package performance also depends on other factors such as the in situ moisture content of the salt. Section 6.4.2.3.3 shows that waste-package performance depends more on brine migration than on any uncertainty in expected thermal conditions (Jansen, 1985).

6.4.2.3.2 Fluid Conditions In Salt. Naturally occurring salt traps small brine inclusions within the salt crystals and along intercrystalline boundaries. When a thermal gradient is applied, solubility differences can cause the brine inclusions to migrate toward the heat source. Salt dissolves at the hot side of the inclusion, moves through the inclusion, and then precipitates at the cool side of the inclusion. When each inclusion reaches a crystal interface, intracrystalline brine migration stops. Intercrystalline movement may then occur

Table 6-30. TEMPV5 Temperature Versus Time at Salt-Overpack Interface for Davis Canyon

Time (No. of years)	Temperature, C	
	CHLW(a)	SFPWR(b)
0.1	187.3	114.0
0.2	199.0	118.8
0.5	211.7	122.8
1	220.0	125.3
2	227.9	127.9
5	236.2	131.3
10	233.6	133.5
20	212.8	132.7
50	156.0	121.1
100	117.1	105.7
200	96.9	91.2
500	76.7	81.2
1,000	60.5	74.2
2,000	48.5	62.1
5,000	36.5	44.0
10,000	33.7	33.7

Note: T_o = 33.7 C (92.7 F).

(a) Commercial high-level waste.
(b) Spent fuel from pressurized water reactors.

along grain boundaries towards the heat source. This section discusses the preliminary analytical approach, data base and uncertainty, and results of the brine-migration analyses.

Analytical Approach. McCauley and Raines (1985) used a finite difference code (BRINEMIG) to predict flow rates of brine migrating toward the waste package. BRINEMIG assumes the salt to have homogeneous and isotropic properties and uses the mass balance principle to calculate the moisture concentration profiles. The BRINEMIG code uses the following empirical equation developed by Jenks and Claiborne (1981, ORNL-5818) to predict brine-migration velocities due to a thermal gradient:

$$\log (V/G) = 0.00656\ T - 0.6036$$

where

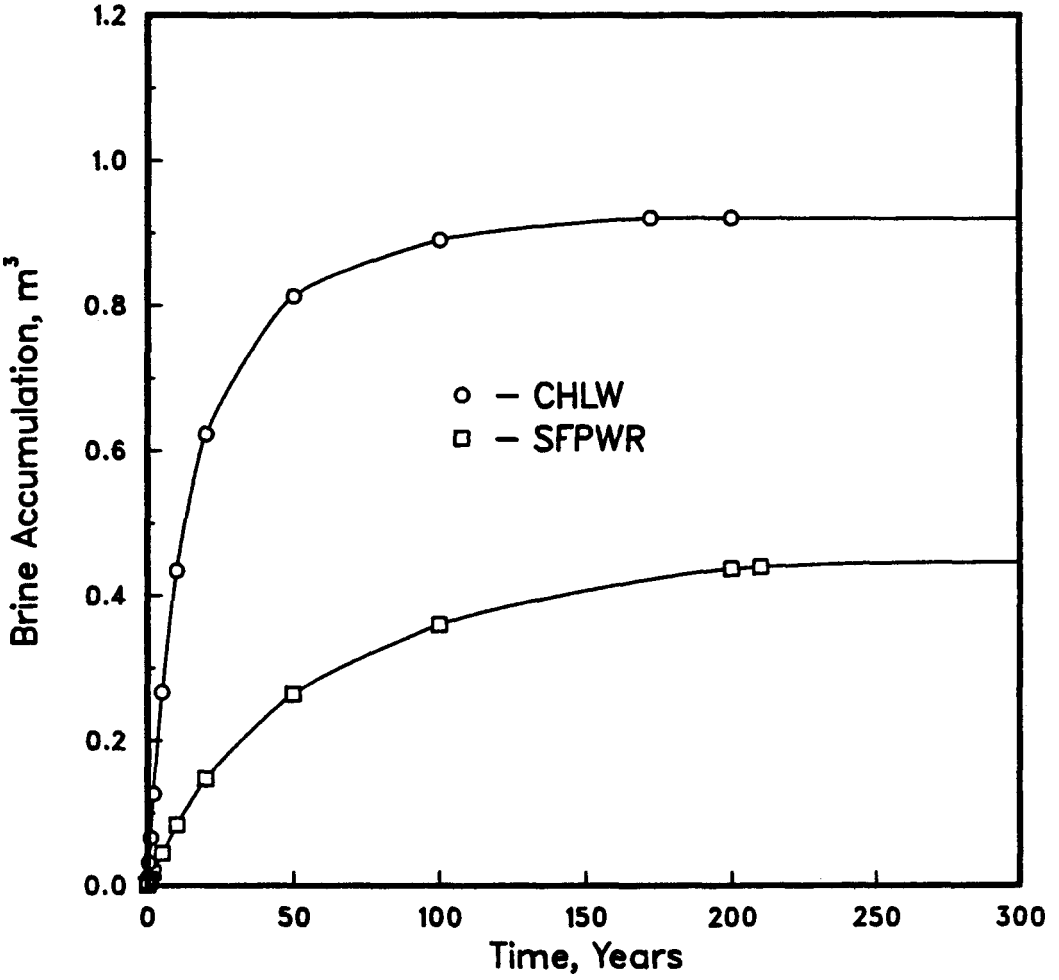
V = velocity of brine migration, centimeters per year
G = thermal gradient, degrees C per centimeter
T = temperature, degrees C.

Jenks and Claiborne (1981, ORNL-5818, Figure 6) used available data to derive the above equation on intracrystalline brine migration to overpredict brine migration due to a thermal gradient. Additional work is required to understand the role of intercrystalline brine flow in the overall process of brine migration. McCauley and Raines (1985) show that BRINEMIG gives brine accumulations that show reasonable agreement with those from the Salt Block II experiment (Hohlfelder, 1980, SAND79-2226). This comparison suggests that BRINEMIG will reasonably predict brine flows even though the code does not consider the brine movement along grain boundaries. Because theoretical considerations (Anthony and Cline, 1971, p. 3380) indicate the existence of a threshold thermal gradient below which brine does not migrate, the analyses also considered cases with and without a threshold gradient.

Data Base and Uncertainty. The amount of brine that flows toward the waste package is directly proportional to the initial brine content of the salt. Gevantman (1981, Table 1.4) reports brine contents by weight for bedded salts between 0.015 and 0.023 percent for Retsof, New York, and 0.67 percent for Hutchinson, Kansas. In general, measured water contents of the Salt Cycle 6 host horizon are less than 0.53 weight percent; however, water contents may be higher in zones containing hydrous evaporite phases, such as carnallite and kieserite (Hite, 1983; Conner, 1983). Conservative calculations yield a maximum brine estimate for Cycle 6 salt of 4.7 volume percent (Sections 3.2.7.1, 6.3.1.2.2). Realistic estimates of brine availability suggest lower values, probably on the order of 1.3 to 3.5 volume percent (Section 3.2.7.1). Use of a high water content will overpredict brine migration for bedded salts. To assure that brine-migration quantities are not underpredicted, the calculations assumed an initial water content of 5.0 volume percent.

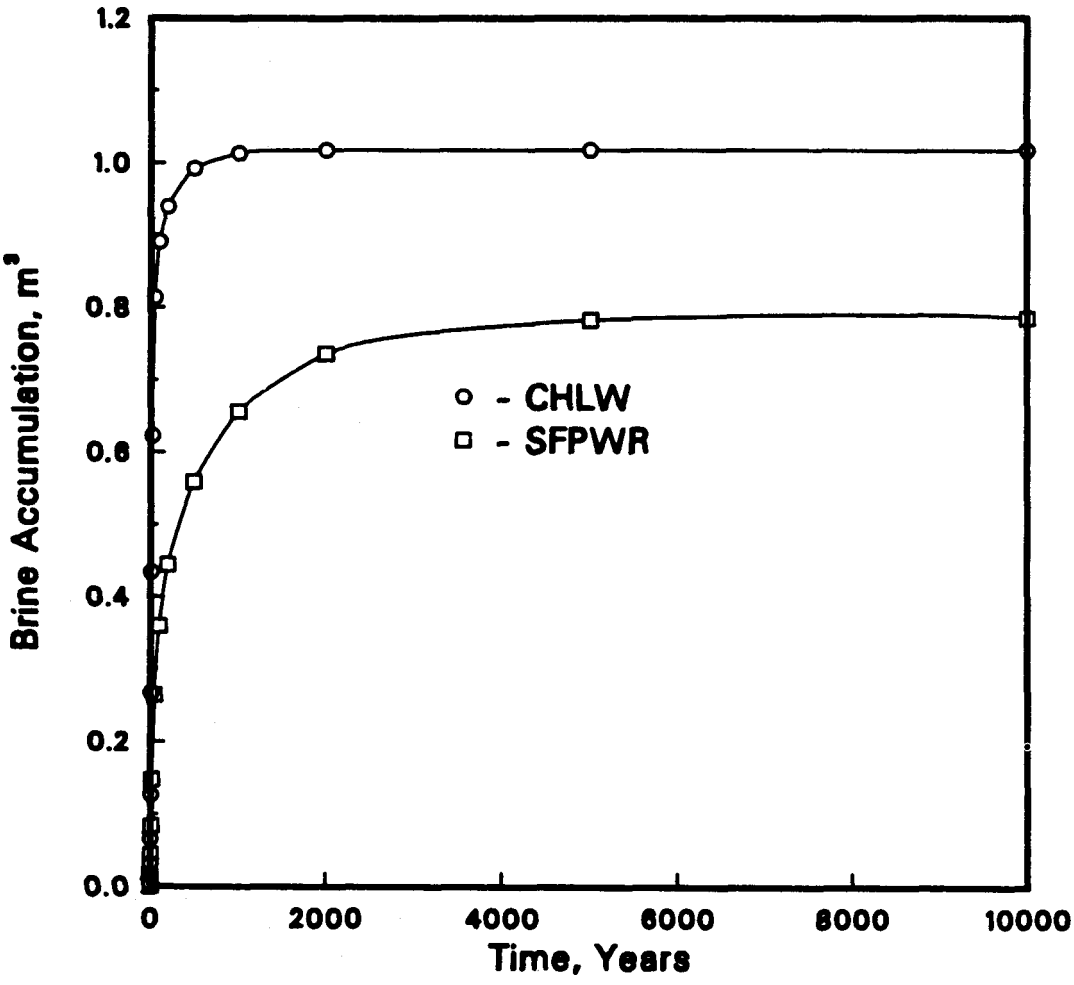
These preliminary calculations used thermal threshold gradients of 0.125 and 0 C (0.225 and 0 F) per centimeter. Jenks and Claiborne (1981, ORNL-5818, pp. 96-103) used 0.125 C (0.225 F) per centimeter for temperatures below 100 C (212 F). A zero thermal threshold gradient gives higher estimates of brine flow to the waste package.

Brine Migration Analyses and Results. BRINEMIG calculates brine flow rates from radial temperature profiles given at various times. BRINEMIG uses temperatures and thermal gradient interpolated from these profiles in the equation developed by Jenks and Claiborne (1981, ORNL-5818). The TEMPV5 code (McNulty, 1985) supplies the temperature profiles to BRINEMIG in tabular form. Figures 6-2 and 6-3 present radial temperature profiles calculated by TEMPV5 for CHLW and SFPWR, respectively. Figure 6-2 shows that CHLW has the steepest thermal gradients. Figures 6-7 and 6-8 present brine accumulation at the waste package with time for threshold gradients of 0.125 and 0 C per centimeter, respectively, the expected and conservative cases. With the threshold gradient, CHLW and SFPWR produce 0.92 and 0.44 cubic meters (33 and 16 cubic feet), respectively, of brine at the waste package. Without a threshold gradient, CHLW and SFPWR produce 1.02 and 0.78 cubic meters (36 and 28 cubic feet) of brine, respectively. A threshold gradient reduces the predicted brine accumulation, especially for SFPWR where temperatures remain high for a much longer time as shown by comparing Figures 6-2



Brine Accumulation at Waste Package With Time and Threshold Gradient of 0.125 °C/cm for Davis Canyon

Figure 6-7



Brine Accumulation at Waste Package
With Time and Zero Threshold Gradient
for Davis Canyon

Figure 6-8

and 6-3. Jansen (1985) and the description in Section 6.4.2.3.3 show that these differences in the accumulated brine do not significantly impact the performance of the waste package.

Other Source of Brine. The dehydration of carnallite may provide the principal source of brine for waste package corrosion. However, elevated temperatures and time are required for carnallite to dehydrate. Also, it is not clear whether carnallite dehydration water will ever reach the waste package environment. The analysis conservatively assumes that brine from this source is immediately available to participate in the brine migration process.

Some of the interbeds may have significant transmissivity and provide a potential conduit for ground water. The siting process is intended to avoid such situations.

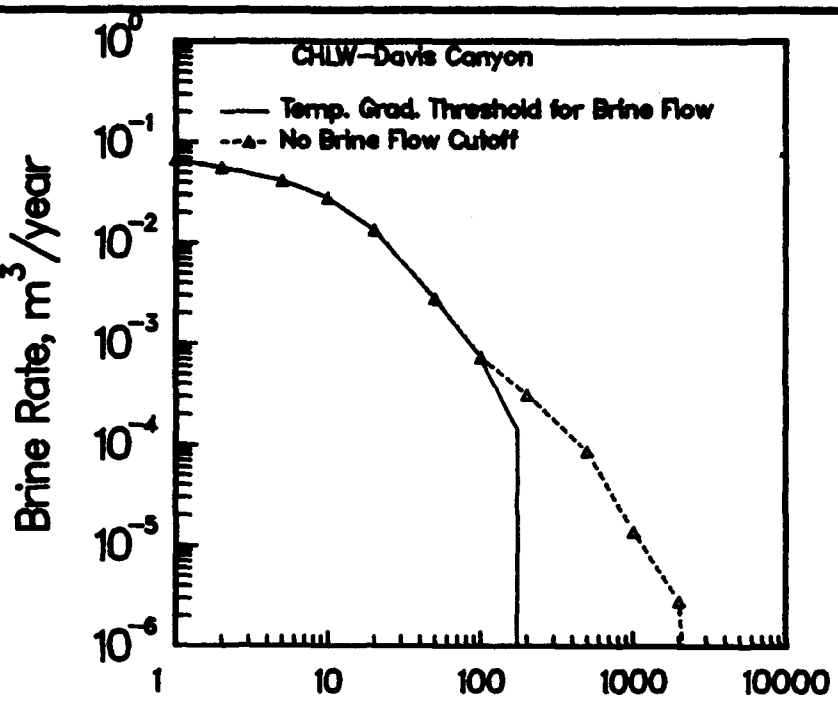
Another possible source of water is the Elephant Canyon aquifer in the unexpected event of an intrusion scenario. As described in Chapter 3, the potentials are such that any flow into the repository level would come from above. Such waters would probably become completely saturated with sodium and chloride prior to reaching the repository level. Some of the calculations in Section 6.4.2.3.3, "Waste Package Performance," consider unlimited flow quantities of "intrusion" brine to give an idea of the effect this source of water would have on package life.

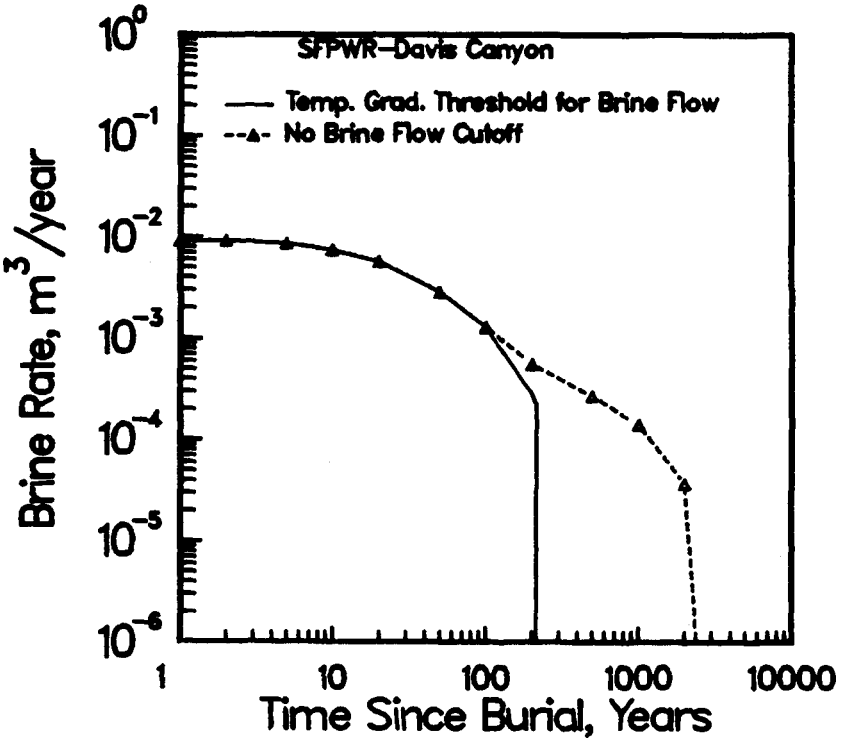
6.4.2.3.3 Waste Package Performance. A preliminary performance assessment of waste-package designs was conducted with the WAPPA waste-package code (Jansen et al., 1984; Jansen, 1985; INTERA, 1983, ONWI-452). Expected conditions for temperature, stress, brine composition, radiation level, and brine flow rate were used as boundary conditions to compute expected corrosion of a thick-walled overpack of low carbon steel. The waste-package failure calculation was essentially a one-dimensional radial geometry integration of corrosion rates uniformly distributed over the outside of the container wall but varying with temperature over a 10,000-year history of the waste package. Package failure was assumed to occur when the corrosion allowance was exceeded and the package was assumed to yield under lithostatic pressure.

Boundary Conditions at the Package Surface. Boundary conditions for temperature, brine flow rate, stress, radiation level, and brine composition at the overpack surface, which are needed by the WAPPA code for the package failure analysis, were estimated by the following methods:

1. Temperature. The temperatures at the surface of the waste package were computed by the TEMPV5 code (based on analytical solutions for decaying short line sources) and were discussed in Section 6.4.2.3.1. The calculated maximum temperatures were 236 C (457 F) at 5 years for the CHLW package surface and 134 C (273 F) at ten years for SFPWR.

2. Brine Flow Rate. Computation of the accumulation of brine flowing to the waste package was discussed in Section 6.4.2.3.2. The brine inflow rates shown in Figure 6-9 were provided as input from BRINEMIG and are needed to properly account for the water in the brine consumed by chemical reaction with the steel overpack at each time step in the computation process. The corrosion reaction stoichiometry consumes the water in 0.32 cubic meters (11 cubic feet) of brine and produces 400 cubic meters (523 cubic yards) of hydrogen gas per centimeter of steel overpack thickness dissolved. Corrosion calculations were carried out for three brine conditions: (1) brine migration with a thermal gradient flow cutoff (the expected condition), (2) brine migration with no thermal gradient flow cutoff, and (3) corrosion with an unlimited excess of brine. The maximum gross accumulated brine volumes (i.e., without chemical reaction) with a thermal gradient cutoff were about 0.92 cubic meters (33 cubic feet) for the CHLW package and about 0.44 cubic meters (16 cubic feet) for the SFPWR package. With no brine flow cutoff, the maximum gross accumulated brine volumes as summed by WAPPA reached 1.02 cubic meters (36 cubic feet) at 10,000 years for the CHLW package and 0.78 cubic meters (28 cubic feet) for the SFPWR package. For corrosion computations, the brine flow was assumed to be





Brine Migration Inflow Rates per Canister

Source: Jansen, 1985.

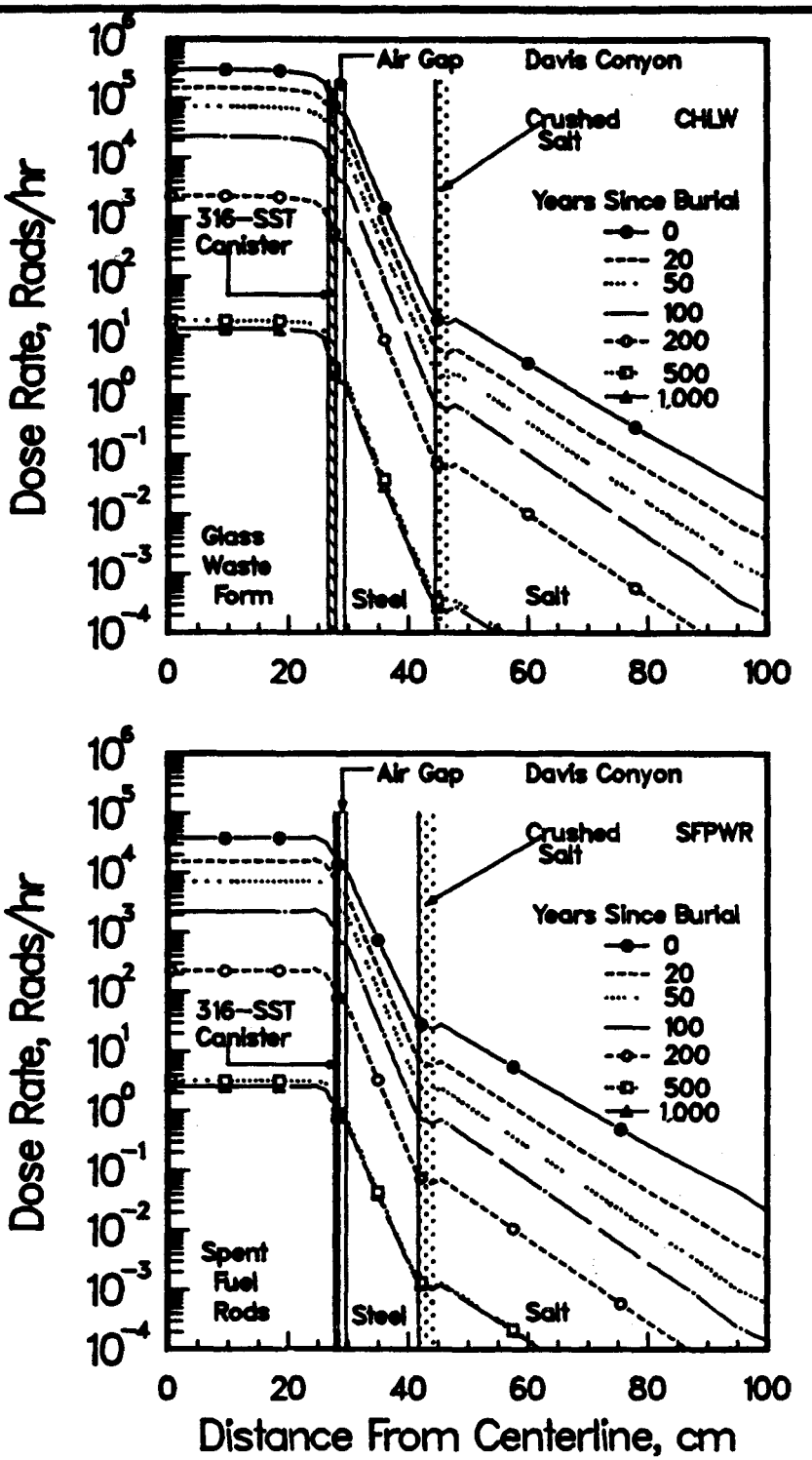
Figure 6-9

uniformly distributed around the radial perimeter and along the length of the overpack.

3. Brine Composition. The composition of the thermally migrating brine (i.e., salt inclusion brine) that contacts the package at Davis is expected to be of high magnesium content (Sections 3.2.7.1 and 6.3.1.2). On the other hand, low to intermediate magnesium content brine is typical of salt dissolution brines used for unexpected events such as brine intrusion scenarios. High-magnesium intrusion brines are not expected in the Paradox Basin because (1) any brine flowing rapidly through the carnallite marker bed above the repository horizon will probably not have the opportunity to saturate with magnesium; (2) any intrusive brine will probably already be saturated with respect to halite, consequently, the extent of carnallite dissolution will be limited by the halite saturation state of brine (both minerals contain chloride); (3) precipitation of magnesium-bearing minerals, some of which exhibit decreasing solubility with increasing temperature, will limit magnesium concentrations; and (4) dilution of high-magnesium brines by low-magnesium fluids is expected to occur (Section 6.3.1.2.3). The compositions of the low-magnesium intrusion brines in Table 6-11 are in reasonably good agreement with that of an experimentally produced composite Paradox Basin dissolution brine as reported by Pederson et al. (1984). Approximately 2,000 mg/l of magnesium have been found in the waters of the Honaker Trail Formation, which immediately overlies the Paradox Formation (McCulley et al. 1984). This concentration is intermediate between the magnesium levels in the two brines used in corrosion tests, and the corrosion resistance of a canister exposed to such solutions is not known. The corrosion tests that have been run to date (Kreiter, 1984) have used WIPP Brine A as a high magnesium content brine and Permian Basin No. 2 brine as a low magnesium content brine. Compositions are shown in Table 6-11 (Kreiter, 1984). Permian Basin No. 2 brine is a modification of the low temperature salt dissolution brine (Permian Basin No. 1) that has been equilibrated at 150 C (302 F) (representative repository conditions) to precipitate anhydrite, which would otherwise have formed a protective scale on the specimen surfaces during the tests.

   It should be emphasized that site-specific Paradox Basin brine compositions are not well known at present. Corrosion data (Table 6-11) are presently available at only two magnesium concentrations; consequently, predictions were based on these values. It is unlikely that a brine, significantly more corrosive than Brine A (Table 6-11), will be identified; however, if better information is obtained during detailed site characterization activities that impacts the corrosion calculations, then the repository or package design can be modified appropriately. The corrosion rates could be lowered, for example, by placing a magnesium getter in the packing surrounding the package, if magnesium is identified to be the problem. Alternately, the overpack thickness could be increased, thermal loading could be decreased, or more corrosion-resistant materials could be used (Section 6.3.1.2.3).

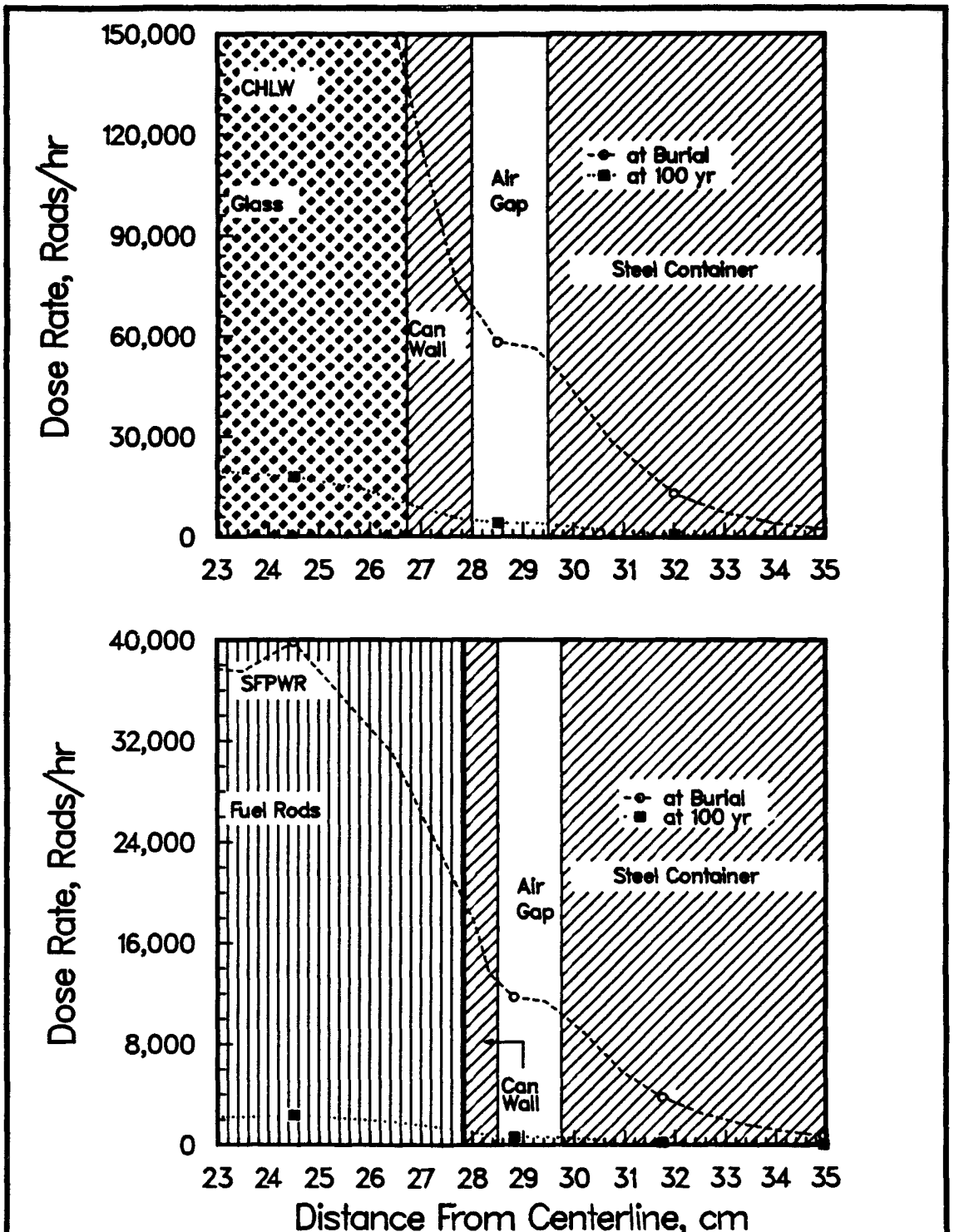
4. The Radiation Field. The ANISN-W code (Oak Ridge National Laboratory and Westinghouse, 1973) with 18 energy source groups, and the DLC-23 cross section library (Oak Ridge National Laboratory and Science Applications Inc., 1973), were used to compute radiation fields in and near the package (Figure 6-10) from gamma energy source terms (ONWI, 1984, BMI/ONWI-545) which had been computed by the ORIGEN-2 code (Croff, 1980, ORNL-5621). The normalized dose rate profile was found to be invariant with time and decayed at precisely the same rate as the total photon rate (Jansen, 1985). This normalized profile and the transient total photon rate were then used directly in the WAPPA code to compute local dose rates at any time. WAPPA made semilogarithmic interpolations of the radiation field in the container wall to estimate the dose at intermediate wall thicknesses. The dose rate (Figures 6-11 and 6-12) at the salt-container interface of the SFPWR package is initially 32 rads per hour and is 21 rads per hour at the CHLW package surface. Both fields decay tenfold during the first 100 years, but the SFPWR radiation field decays less than the CHLW field at times near 1,000 years, because it contains more long-lived actinides. It is clear from Figure 6-13 that any radiation field below



Radiation Fields at Waste Package – Material Interface

Source: Jansen, 1985.

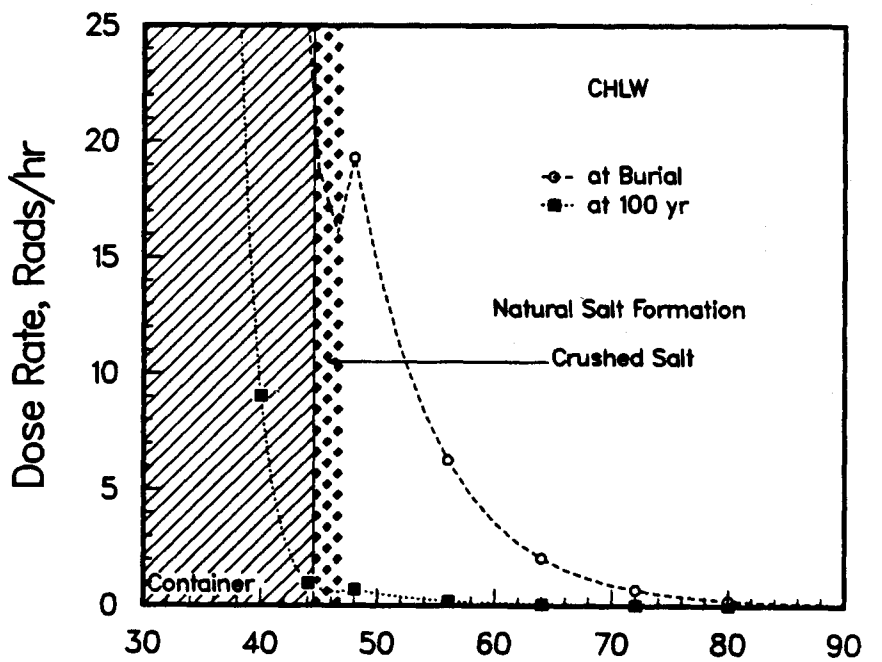
Figure 6-10

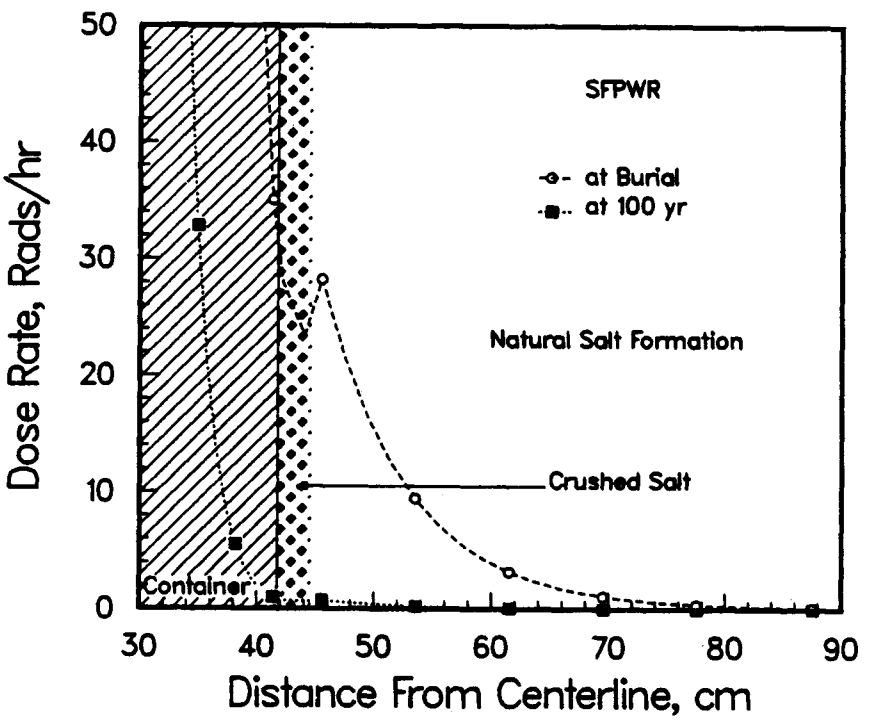


Radiation Fields at Waste Form–Container Interface

Source: Jansen, 1985.

Figure 6-11

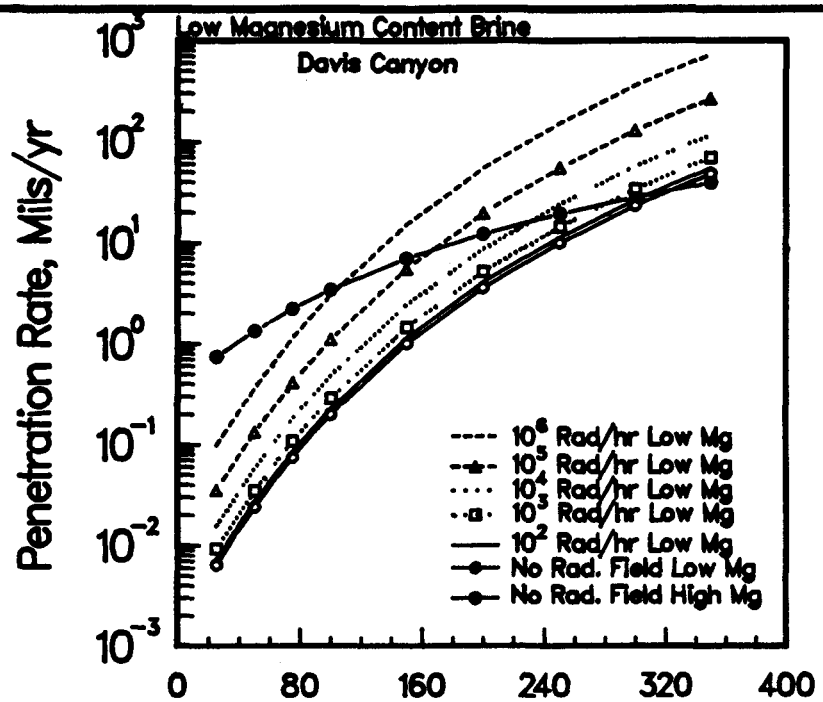


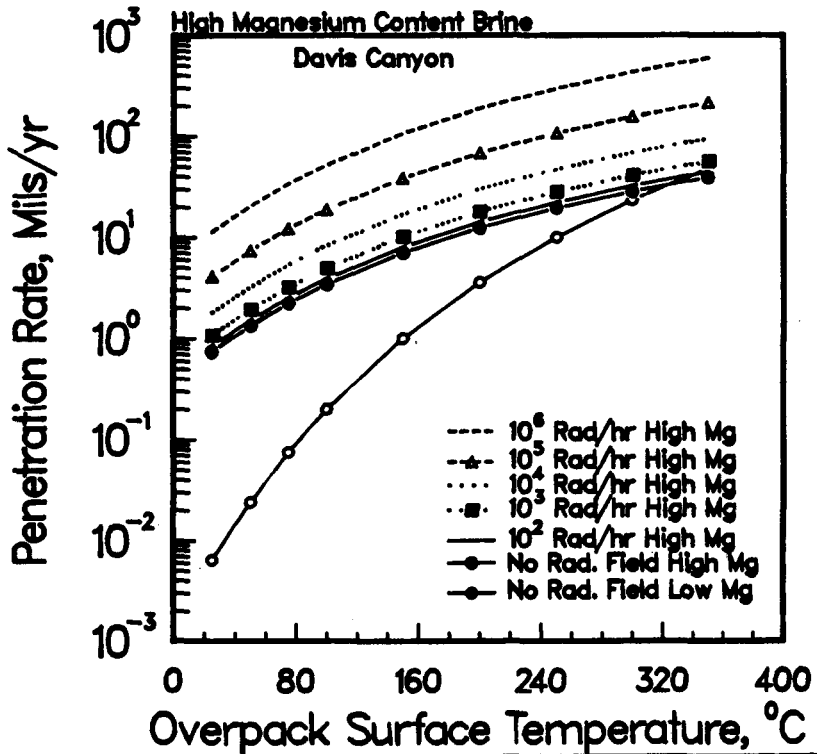


Radiation Fields at Container Crushed Salt Interface

Source: Jansen, 1985.

Figure 6-12





Effect of Radiation Field on Corrosion Rates of Low Carbon Steel Container in Brines

Figure 6-13

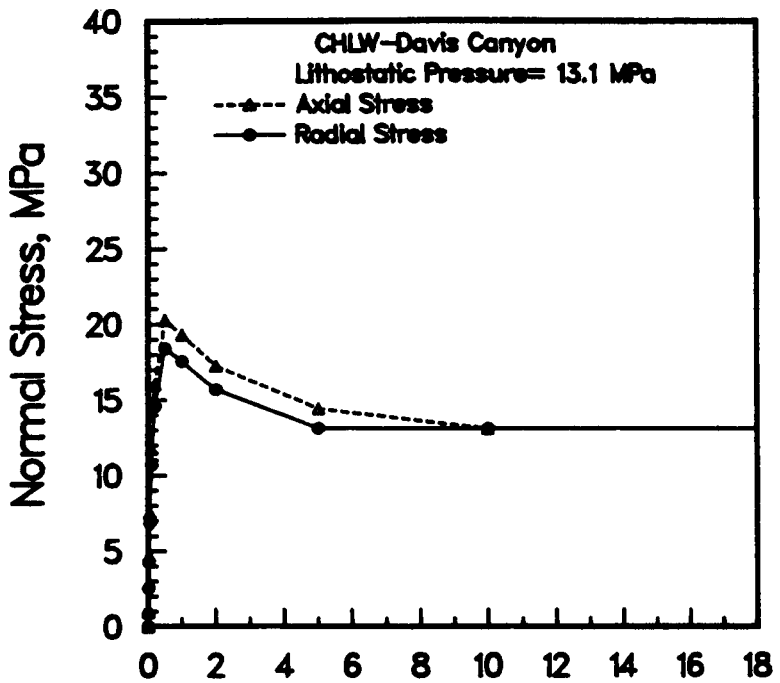
several hundred rads per hour should not produce a significant effect on the corrosion rate unless highly energy-dependent radiation damage effects to salt prove to be more significant than current estimates (Levy, 1983). This observation must be tempered by the fact that if appreciable corrosion penetrates deep into the overpack very rapidly (this is not present at expected uniform corrosion conditions), then the radiation field will be much higher than at the uncorroded surface, and its exact value there may be high enough to require more reliable estimates of the radiation field.

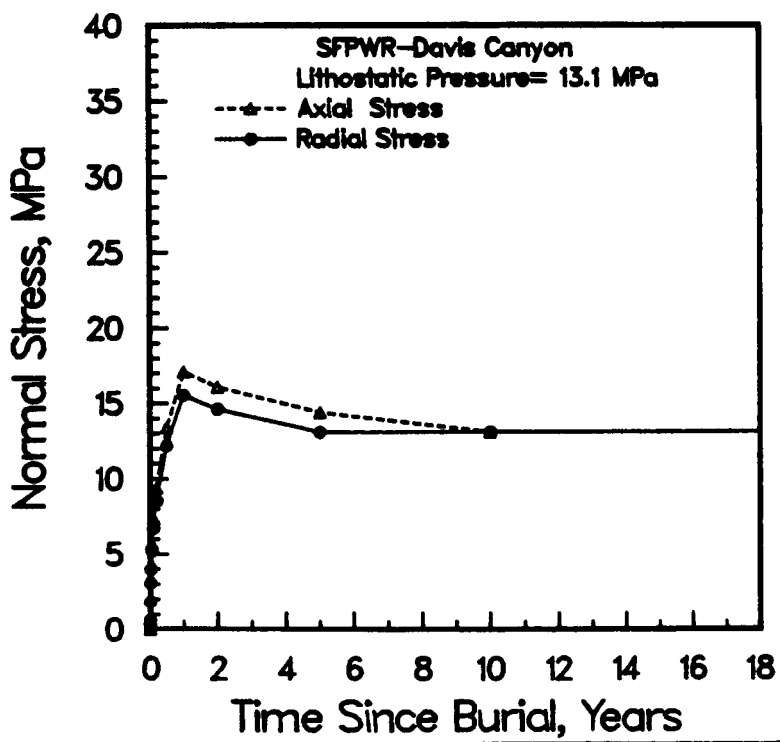
5. Corrosion Rates. Corrosion rates of low carbon steel are dependent on temperature, brine composition, and radiation level. The estimates made by R. E. Westerman of Pacific Northwest Laboratory (PNL) from preliminary data (Kreiter, 1984) were correlated and extrapolated (Jansen, 1985) as shown in Figure 6-13. More recent data now available (Westerman et al., 1983) differ only in detail. Westerman et al. describe the estimates as follows:

> The supplied values were estimated on the basis of the limited corrosion rate data presently available (07/21/83). These data have been primarily obtained in mild and low-alloy steels and nodular cast irons in simulated Permian Basin intrusion brine at 150 C in irradiated and unirradiated tests in flowing autoclave systems (PNL work), and in unirradiated Brine A at 250 C in static autoclave systems (PNL and Sandia work). The data on irradiated simulated intrusion brine at 250 C and irradiated Brine A amount to only a few very short-term tests (Sandia work). Because of the uncertainties involved in estimating corrosion rates without a clear understanding of the effects of the independent test variables mentioned (temperature, brine composition, irradiation intensity) on the rate-limiting mechanism(s) of the corrosion process, the estimated values in the table may be in error by as much as a factor of five, with the highest degree of uncertainty in the 250 C and high irradiation-intensity regimes.

The reference corrosion rate was 0.025 millimeter (0.001 inch) per year at 150 C (302 F) for the low magnesium brine, and the temperature effect was introduced by a free energy of 10.1 kilocalories per mole. The reference condition was 0.18 millimeter (0.007 inch) per year at 150 C (302 F) for the high magnesium brine and the temperature effect was introduced by a free energy of 4.5 kilocalories per mole. Intermediate oxidizing species that may control the corrosion rate were found to vary with the square root of the dose rate in preliminary computer modeling activities (Kreiter, 1984). Therefore, the effect of radiation on corrosion was derived by fitting an apparent square root dependency to the corrosion data. The same radiation enhancement factor for corrosion, which produces about a twentyfold increase in corrosion rate at 10^6 rads per hour, was applied at all temperatures. For expected dose rates at container surfaces of 20 to 40 rads per hour, the increase in corrosion rate is clearly negligible.

6. Boundary Stresses. Salt creep is expected to close the borehole around the waste package during the first year. Maximum normal stress due to thermal gradients may be exerted on the package during the first few years after burial, with a gradual decay to lithostatic pressure during the first decade after burial. The peak values and the decay histories of the stresses are currently poorly defined. An analysis of similar behavior at the Asse salt dome in Germany, showed the stresses to be always compressive and verified a creep law model for repository conditions in that salt (Prij and Vons, 1984). For the purpose of this preliminary analysis, a 25-percent excess horizontal (radial) compressive stress and a 35-percent excess vertical axial compressive stress (Figure 6-14) have been assumed relative to the lithostatic pressure, peaking near one year after burial (Loken et al., 1984). Further, it has also been assumed that the 5.0-centimeter (1.97-inch) CHLW and 2.5-centimeter (.98-inch) SFPWR allowances for container corrosion used by Westinghouse (Westinghouse Electric Corp., 1983, ONWI-438) apply at the long-term





Stress Boundary Conditions at Waste Package Midplane

Source: Jansen, 1985.

Figure 6-14

lithostatic pressure in the salt formation. We did not use the mechanical submodel in the WAPPA code for stress calculations. Instead, when the uniformly corroded thickness reached these values, the overpack was assumed to yield and the barriers breach, allowing brine to contact the waste form.

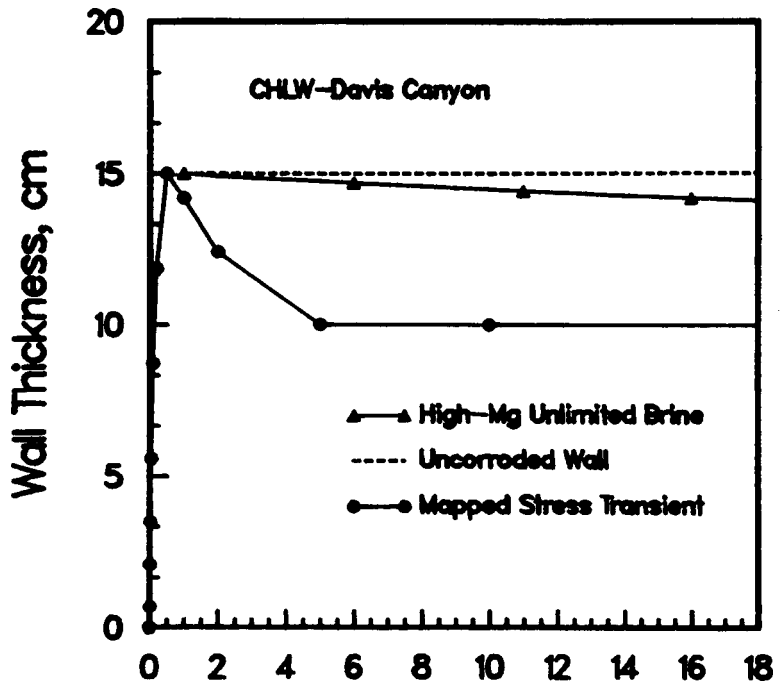
Failure of Waste Packages. A waste package has not actually failed until radionuclides are transmitted beyond the waste package boundary. The process is initiated by the in-migration of brine and the onset of corrosion of the overpack. This process chemically consumes oxygen from the water in the brine. If, and when, all the oxygen is consumed, the process stops. Even if corrosion persists until the overpack is penetrated, additional barriers exist in the form of the stainless steel canister and Zircaloy clad for spent fuel, and the waste form itself for CHLW. Even though the clad may not be intact, and stainless steel is not especially tolerant of salt brines, zirconium and iron tend to oxidize readily and further consume oxygen to help ensure anoxic conditions in any brine which might remain unreacted. In addition, these materials and their corrosion products physically retard the movement of fluids toward the interior of the waste package, and thus, further inhibit the release of radionuclides. Furthermore, brine must dissolve the fuel pellet (for SF) or the glass (for CHLW), along with the radionuclide elements. As will be discussed later, many nuclide elements have low inherent solubilities, and therefore matrix solubility is not an important factor. However, others (e.g. cesium, iodine) do not have inherently restrictive elemental solubilities but are significantly retarded by considerations of matrix solubility. None of these factors is considered in this preliminary analysis.

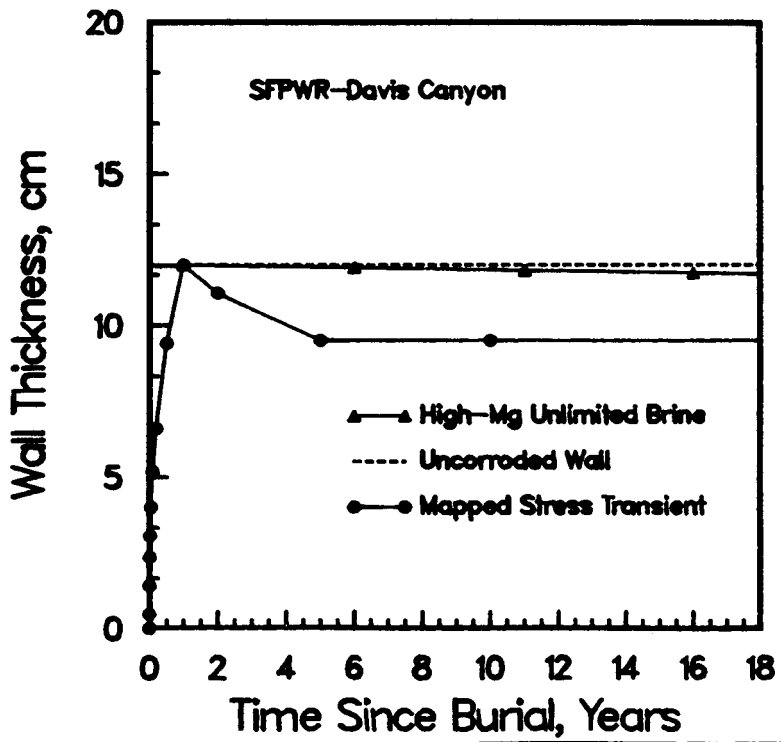
In addition to ignoring the above-mentioned conservative factors, the distribution of failure times of waste packages would spread releases over time, perhaps over periods longer than 10,000 years. For purposes of this preliminary analysis, all waste packages are assumed to fail simultaneously at the calculated time the portion of the overpack, that is allocated for a corrosion allowance, is corroded away.

Corrosion and Failure of the Overpack. Corrosion of the overpack with unlimited brine flow quantities during the first 20 years is compared in Figure 6-15 with the estimated wall thickness at which the overpack would fail. The difference between lithostatic and maximum failure thicknesses has been normalized to equal the corrosion allowance. The effect of the stress transient (Figure 6-14) is negligible by the time corrosion becomes appreciable for both CHLW and SFPWR packages. Thus, if the package is designed to withstand the early high stresses prior to the occurrence of significant corrosion without a corrosion allowance, a detailed analysis of transient stresses is not necessary in the WAPPA code calculation.

Unlimited brine flow provides unrealistically high corrosion rates for a long-term extrapolation. At longer times, different results are produced for thermal-gradient driven inflowing brine (the expected condition at Davis Canyon) than with an unlimited amount of brine available (Figure 6-16 and Table 6-31). Numerous corrosion mechanisms exist, e.g., uniform corrosion, stress corrosion cracking, pitting, intergranular attack, etc. Low carbon steel, the material selected for the overpack, is not especially susceptible to pitting and other non-uniform corrosion phenomena as confirmed by corrosion experiments (Kreiter, 1984; Westerman et al., 1983). The brine is expected to distribute uniformly over the package surface because of the crushed salt backfill. If the brine does distribute uniformly over the overpack surface, the analyses indicate that brine corrodes only 3.0 centimeters (1.18 inches) of the 5.0 centimeter (1.97 inches) corrosion allowance for CHLW and 1.4 centimeters (.55 inch) of the 2.5 centimeter (.98 inch) corrosion allowance for SFPWR. The analyses further indicate that corrosion would then stop indefinitely because no more water would be available to react with the remaining iron in the overpack. Reduction in the surface covered by brine would cause a decrease in the package lifetime. A similar result would be obtained if pitting or stress corrosion cracking increased the local penetration.

Corrosion of the waste package in unlimited quantities of intrusion brines with low magnesium content is shown in Figure 6-17 and Table 6-31. This approximates the condition that might occur in the event of an intrusion scenario. With uniform corrosion rates, both packages are intact at 10,000 years, and the result is independent of brine distribution over

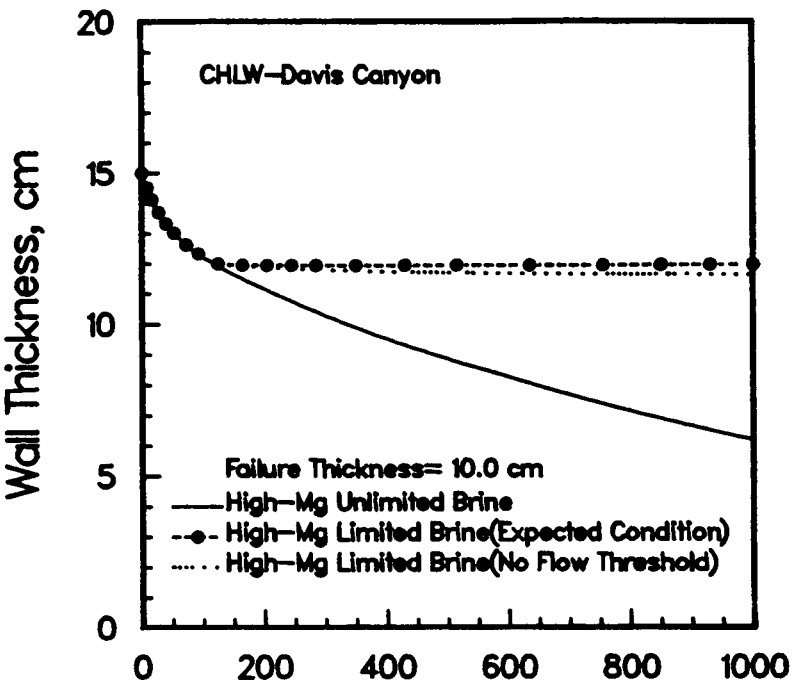


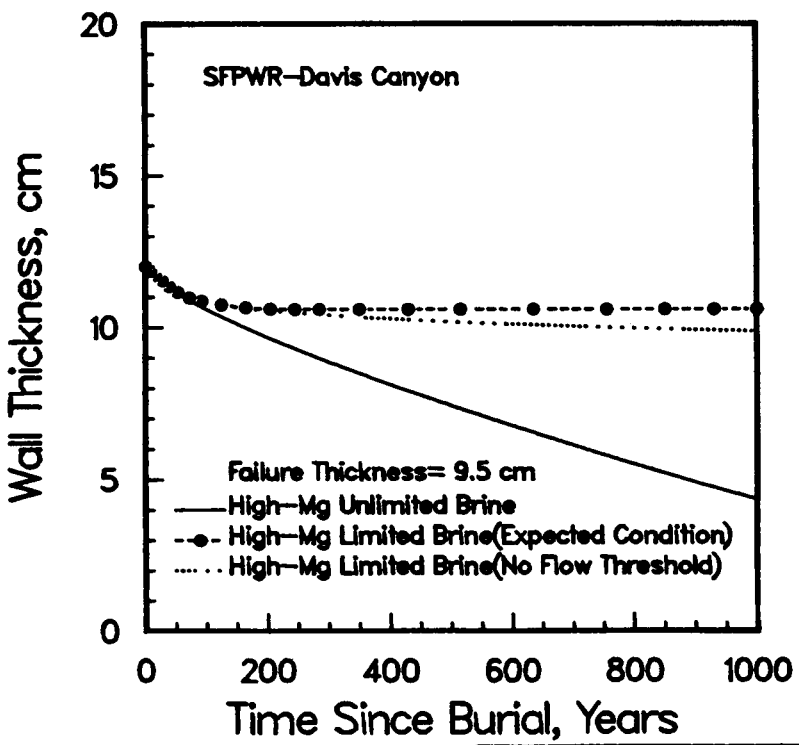


Comparison of Corrosion With Transient Failure Thickness of Container

Source: Jansen, 1985.

Figure 6-15





Effect of Brine Rate on Corrosion of the Container

Source: Jansen, 1985.

Figure 6-16

the package surface. At this time, 1.5 centimeters (0.59 inch) of the 5.0 centimeters (1.97 inches) CHLW corrosion allowance and 1.0 centimeter (0.39 inch) of the 2.5 centimeters (0.98 inch) SFPWR corrosion allowance have been corroded from the overpacks.

With the low corrosion rates in low-magnesium intrusion brine, the results for expected conditions are not sensitive to nonuniform distribution of limited quantities of brine over the package surface. On the other hand, with expected high-magnesium brines and higher corrosion rates, the conditions for promoting nonuniform brine distribution should be avoided. A measure of the sensitivity of the uniform brine distribution results to nonuniformity of brine distribution is the fraction of coverage of the overpack surface by the limited amount of brine at which the available water is just sufficient to permit uniform corrosion of the complete corrosion allowance. With surface coverage less than this critical value, the corrosion rate is governed only by the chemical reaction rate, which causes failure at times less than the 300-year minimum package lifetime mandated by 10 CFR Part 60. The critical surface coverages for the Davis Canyon site is 61 percent for CHLW and 57 percent for SF. Surface coverages appreciably higher than these values would need to be maintained to give package lifetimes approaching 1,000 years. Emplacement procedures, such as the oversize of the borehole, whether it is backfilled, the void space in the crushed salt backfill, and the water content of the backfill and of the salt formation itself, are expected to affect the uniformity of brine distribution over the package surface.

Only uniform corrosion has been reported in the overpack material tests at saturated anoxic conditions by PNL (Kreiter, 1984; Westerman et al., 1983). However, although perfectly uniform corrosion is a useful concept, it is a theoretical limit. Some nonuniform corrosion occurs even in the most uniformly corroded specimens. Limits will eventually be obtained from test programs for the degree of nonuniformity of the attack of brine upon the overpack material under expected conditions. At the present time we can only make parametric analytical studies of the hypothetical effect of pitting ratio* on the waste package integrity.

For small pitting ratios, the pit does not penetrate through the corrosion allowance of the container before corrosion is halted by lack of water availability or before the 10,000-year computation period is exceeded. For larger pitting ratios, the pit penetrates the corrosion allowance thickness in a shorter time than uniform corrosion and the overpack is then assumed to fail mechanically, breaching the container and permitting radionuclides to be leached from the waste form through the breach. At some pitting ratio designated here as the critical value, the pit penetrates the corrosion allowance at exactly 10,000 years. This then becomes a measure of how sensitive the uniform corrosion results would be to pitting or crevice corrosion, if one or the other occurred. This is a very conservative assumption. In fact, this mechanical failure may never occur, and it may be necessary for a pit to penetrate through the entire container wall thickness to permit brine to contact the waste form.

For the Davis Canyon site at the expected conditions for thermally migrating brine, the critical pitting ratio is 1.65 for CHLW and 1.76 for SF. This low ratio indicates a high sensitivity of computation results to nonuniform corrosion. Conditions that cause pitting should be identified and avoided if possible. On the other hand, for the unlimited volume of low-magnesium intrusion brines, the critical pitting ratio is about 3.3 for CHLW and 2.5 for SF packages at 10,000 years. With intrusion brine, the computed results are much less sensitive to a pitting attack assumption than with inclusion brine.

If it were possible for there to be unlimited quantities of the high magnesium brine to contact the waste package, Table 6-30 indicates failure of overpacks at 336 and 220 years for CHLW AND SFPWR respectively. The improbability of high-magnesium brine formation is discussed in Section 6.3.1.2.3. However, this case is included to give a lower bound on package lifetime.

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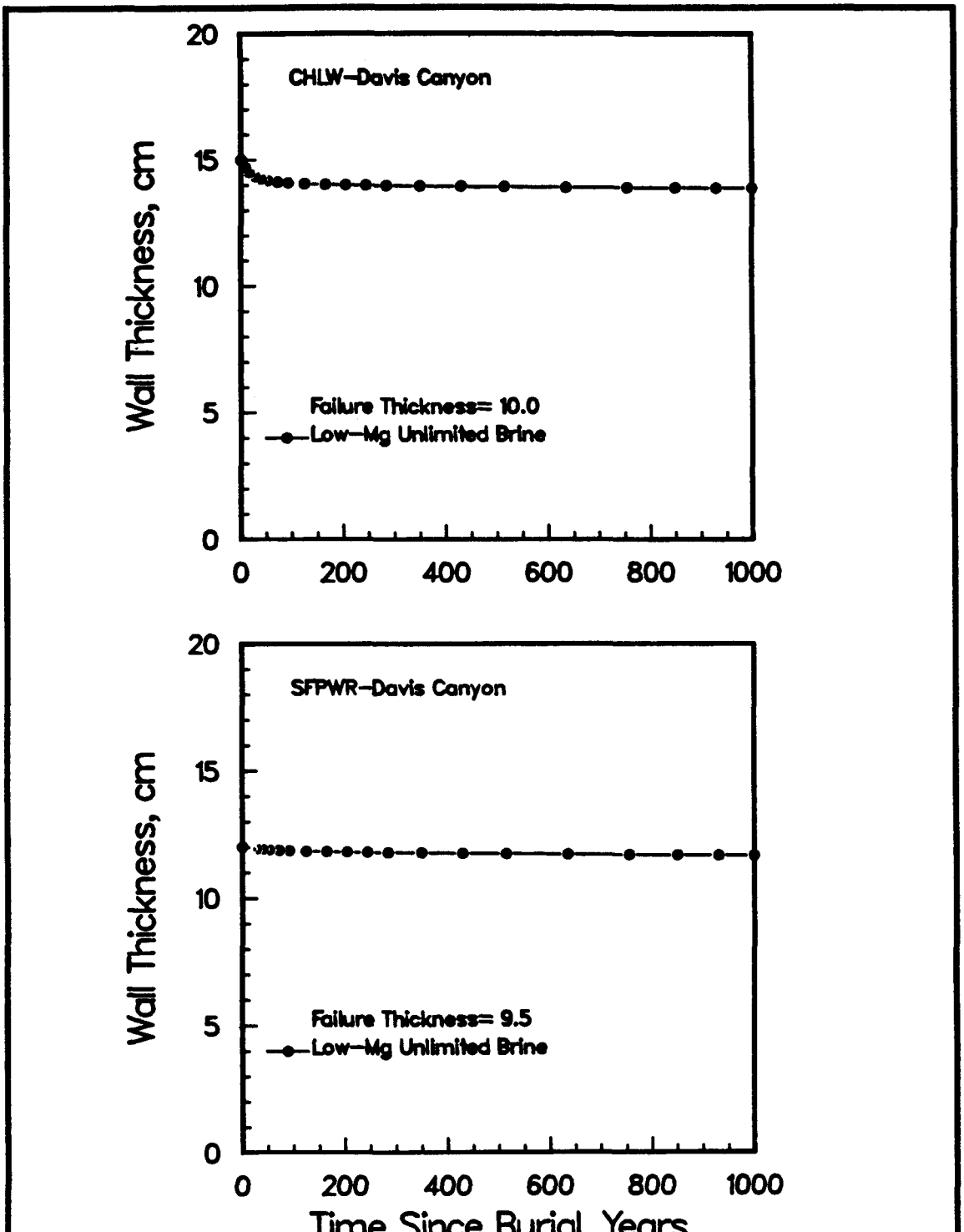
*Pitting ratio is defined here as the ratio of the uniformly corroded thickness plus the depth of the pit or crack to the uniformly corroded thickness.



Corrosion and Failure of Waste Package in Low-Magnesium Brine

Source: Jansen, 1985.

Figure 6-17

Table 6-31. Effect of Brine Availability on Failure of Waste Packages in Davis Canyon

Corrosion Conditions	Uniformly Corroded Thickness, cm	Failure Time,[a] years	Condition at 10,000 years
CHLW	EXPECTED CONDITION - THERMALLY MIGRATING BRINE		
High-Mg Limited Brine Volume	3.0	(b)	Intact
	UNEXPECTED CONDITIONS - THERMALLY MIGRATING BRINE		
High-Mg Limited Brine Volume (no brine flow threshold)	3.3	(b)	Intact
High-Mg Unlimited Brine Volume	5.0	336	Failed
	UNEXPECTED CONDITIONS - INTRUSIVE SALT DISSOLUTION BRINE		
Low-Mg Unlimited Brine Volume	1.5	Greater than 10,000	Intact
SFPWR	EXPECTED CONDITION - THERMALLY MIGRATING BRINE		
High-Mg Limited Brine Volume	1.4	(b)	Intact
	UNEXPECTED CONDITIONS - THERMALLY MIGRATING BRINE		
High-Mg Limited Brine Volume (no brine flow threshold)	2.5	2750	Failed
High-Mg Unlimited Brine Volume	2.5	220	Failed
	UNEXPECTED CONDITIONS - INTRUSIVE SALT DISSOLUTION BRINE		
Low-Mg Unlimited Brine Volume	1.0	Greater than 10,000	Intact

(a) "Failed" means that a thickness equal to the corrosion allowance has been corroded uniformly. "Failure Time" is the time that this occurrence takes place.
(b) Failure is not ever expected under these conditions.

It is conceivable that corrosion could be limited by diffusion of brine or intermediate species through a thick, adherent iron oxide layer or anhydrite precipitate. This analysis included no consideration of any limitation of that type.

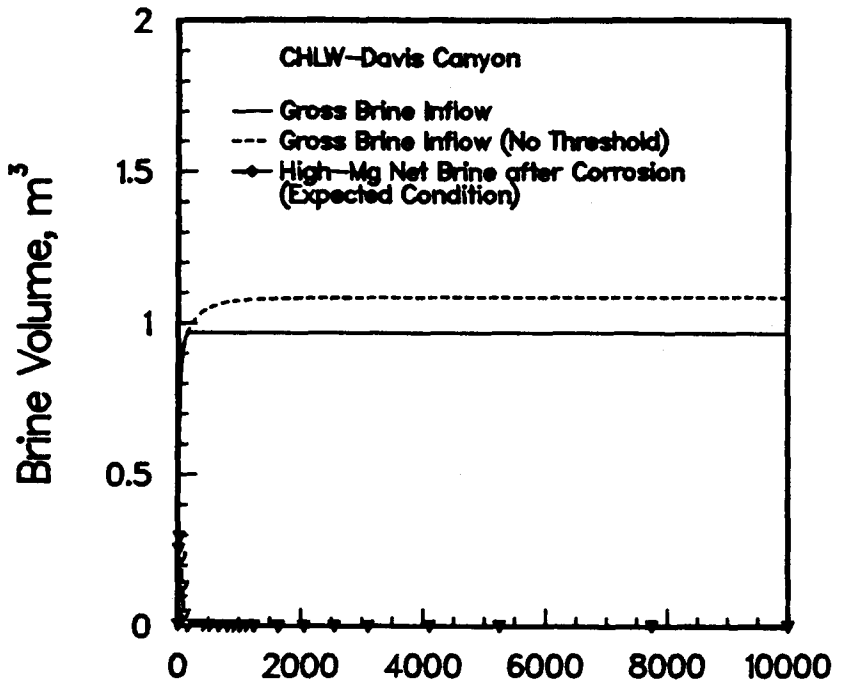
During the period shortly after emplacement, generated hydrogen can escape from the emplacement hole, which may or may not be promptly backfilled. Gas can continue to escape after backfilling and prior to consolidation of the backfill material. If at any time the reconsolidating salt begins to trap the gas, the increase in gas pressure will be limited by salt creep and stress redistribution (just as thermal stresses are relieved) and by diffusion of hydrogen gas through the salt matrix. If moisture contacts the waste package as a vapor, there will be an actual volume contraction and a decrease in gas pressure as corrosion occurs.

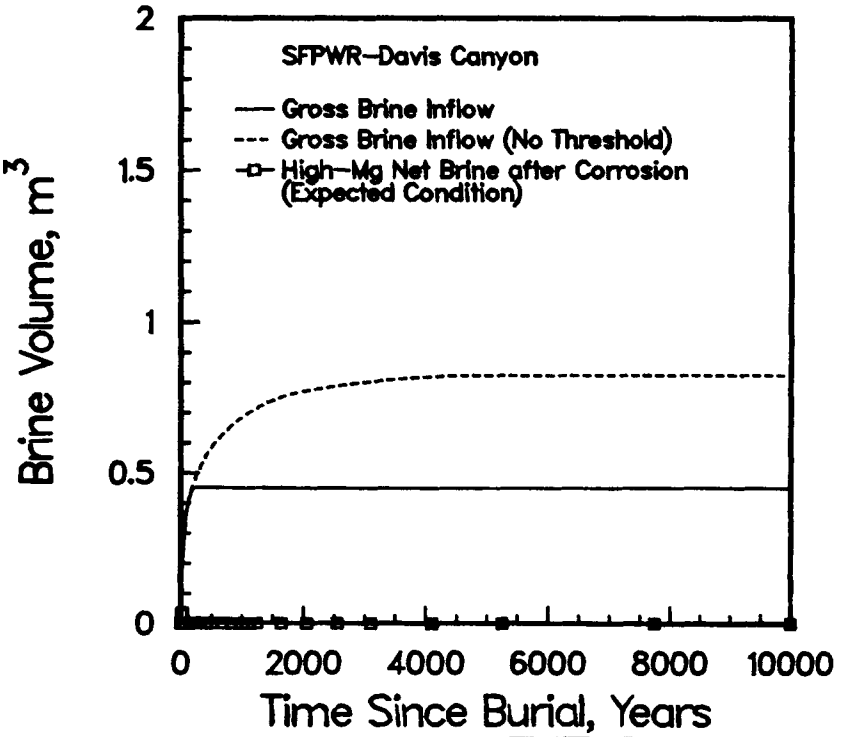
6.4.2.3.4 Release Rate From the Engineered-Barrier Subsystem. For the purpose of this preliminary performance assessment, the engineered-barrier subsystem boundary is the outside surface of each overpack of each waste package. Nuclide releases from the engineered-barrier subsystem to the geologic subsystem are assumed to commence at the time of failure of the overpack and are assumed to be limited only by the quantity of each nuclide that would dissolve into the quantity of brine available (ignoring the consumption of brine by chemical reaction with the overpack). Synergistic effects which result in lower solubilities such as saturation with iron or the presence of carbon in carbides are ignored.

Brine accumulations around the packages with and without consumption of brine by corrosion are shown in Figure 6-18 for both packages in Davis Canyon. This shows that essentially all of the brine reaching the package is promptly used up by chemical reaction with the iron in the overpack, with the exception of the CHLW package during the first 100 years after burial. The net brine left approaches zero for the CHLW package before 200 years so that the conclusion for CHLW is identical to that of SFPWR. The net brine left after chemical reaction with the steel overpack will be much less than the gross accumulated brine volume. This will reduce the potential for leaching of radionuclides from the waste form. As a conservative assumption, however, the gross volume of brine is used to compute an upper limit to the release of radionuclides across the package surface. This has been done using the solubility limits given in Table 6-32, which are taken from the National Academy of Sciences (NAS) Waste Isolation Panel (WISP) Report (Pigford, 1983), with addition of estimated values for saturated radium concentrations in natural brines (Langmuir, 1983) and nominal values for highly soluble cesium chloride and sodium iodide salts in water and for carbon in carbonate-saturated ground water (Card and Jansen, 1975). Several data sets exist from which solubility information can be drawn (Fournier and Rowe, 1977; Muller et al., 1981, SAND81-0557; Rai et al., 1981; Rai et al., 1983; Rai and Ryan, 1982; Rai and Ryan, 1984; Ryan and Rai, 1983; Van Luik and Jurinak, 1979); none of these is based on site-specific conditions. For the purpose of this preliminary assessment, the information from Pigford (1983) has been selected as generally representative of expected solubility values.

It should be noted that there are probably inadequacies in any currently available data set. The effects of high ionic strength solutions, temperature, and pressure on radionuclide solubility are not completely understood. Also, the thermodynamic data base for various radionuclide solution species is subject to uncertainties and estimations, and, therefore, is not adequate for definitive calculations. One computer code, EQ3/EQ6, is currently being modified for use on repository conditions (INTERA, 1983, ONWI-472). The radionuclide release calculations in Sections 6.4.2.3 and 6.4.2.4 will continually be updated with state-of-the-art codes as new data and computational methods become available. Solubilities of most radionuclides in brine are a strong function of Eh and pH; neither are expected to be significantly affected by the near-field radiation field of only about 20 rad/per hour (Sections 6.3.1.2.2 and 6.3.1.2.3). Activities during site characterization will further document the effects of radiolysis on oxidation-reduction potential at repository-relevant dose rates. Solubilities expected in anoxic brines would be lower than the WISP estimates (Pigford, 1983).

The preliminary results for CHLW and SFPWR packages are compared in Tables 6-32 and 6-33 with the final EPA 40 CFR Part 191 individual nuclide limits at the repository site boundary prorated to each package. It is required that the sum of these release ratios at the accessible environment must not exceed unity. For all elements except cesium, iodine, and possibly





Net Accumulated Brine During Corrosion of the Waste Package

Source: Jansen, 1985.

Figure 6-18

Table 6-32. Davis Canyon CHLW Package. Comparison of Solubility and Release at a Failed Waste Package Boundary with EPA Discharge Limits to the Accessible Environment

Element	Solubility,[a] grams/m^3	Package Inventory,[b] grams	Dissolved in Brine, grams	Nuclide	EPA Limit,[c] Curies per 1000 MTHM	Ratio of Radioactivity[b] in Brine to EPA Limit	Total Volume of Saturated Brine to Reach EPA Limit, m^3
Carbon	0.06	1,608[d]	5.5E-02	C-14	100	0.51E-3	1.8E+3
Selenium	0.001	539	9.2E-4	Se-79	1,000	0.69E-6	1.3E+6
Strontium	0.8	3,375	0.74	Sr-90	100	0.098	9.4
Technetium	0.001	7,368	9.2E-4	Tc-99	10,000	0.16E-6	5.7E+6
Tin	0.0001	915	9.2E-5	Sn-126	1,000	0.77E-7	1.2E+7
Iodine	600,000	2,238[d]	2,238	I-129	100	0.31	Not saturated
Cesium	600,000	13,664	13,664	Cs-135	1,000	0.34	Not saturated
				Cs-137	1,000	80 (meets limit by decay at 490 years)	
Radium	0.00042	1.6E-4	1.6E-4	Ra-226	100	0.16E-3	Not saturated
Thorium	0.001	0.09	9.2E-4	Th-230	10	0.16E-3	5.7E+3
				Th-232	10	0.17E-9	5.4E+9
Uranium	0.001	46,465	9.2E-4	U-233	100	0.89E-10	1.0E+10
				U-234	100	0.22E-8	4.2E+8
				U-235	100	0.17E-10	5.3E+10
				U-236	100	0.26E-9	3.5E+9
				U-238	100	0.31E-9	2.9E+9
Neptunium	0.001	5,940	9.2E-4	Np-237	100	0.67E-6	1.4E+6
Plutonium	0.001	540	9.2E-4	Pu-238	100	0.54E-4	1.7E+4
				Pu-239	100	0.29E-4	3.2E+4
				Pu-240	100	0.10E-3	9.1E+3
				Pu-241	1,000	0.26E-6	3.6E+6
				Pu-242	100	0.15E-6	6.2E+6
Americium	0.0001	3,731	9.2E-5	Am-241	100	0.26E-3	3.6E+3
				Am-243	100	0.40E-5	2.3E+5
Curium	0.001	8.6	9.2E-4	Cm-244	100	0.14E-4	6.6E+4

Table 6-32. Davis Canyon CHLW Package. Comparison of Solubility and Release at a Failed Waste Package Boundary with EPA Discharge Limits to the Accessible Environment
(Page 2 of 2)

	10,000 year Inventory, grams	Nuclide	Time, years: 200	300	500	1,000	10,000 — Specific Activity, Ci/g	Time, years: 200	300	500	1,000	10,000 — Ratio of Radioactivity in Brine to EPA Limit
Carbon	1,607	C-14	9.0E-3	8.9E-3	8.7E-3	8.2E-3	2.8E-3	5.1E-4	5.1E-4	5.1E-4	4.7E-4	1.6E-4
Selenium	533	Se-79	7.2E-3	7.2E-3	7.2E-3	7.2E-3	6.6E-3	6.9E-7	6.9E-7	6.9E-7	6.9E-7	6.3E-7
Strontium	3,351	Sr-90	1.4	0.13	1.1E-3	7.5E-9	0	1.1	9.8E-2	8.5E-4	5.7E-9	0
Technetium	7,139	Tc-99	0.017	0.017	0.017	0.017	0.017	1.6E-7	1.6E-7	1.6E-7	1.6E-7	1.6E-7
Tin	898	Sn-126	8.1E-3	8.1E-3	8.1E-3	8.1E-3	7.7E-3	7.7E-8	7.7E-8	7.7E-8	7.7E-8	7.3E-8
Iodine	2,237	I-129	1.3E-4	1.3E-4	1.3E-4	1.3E-4	1.3E-4	0.31	0.31	0.31	0.31	0.31
Cesium	13,597	Cs-135	2.4E-4	2.4E-4	2.4E-4	2.4E-4	2.4E-4	0.34	0.34	0.34	0.34	0.34
			0.57	0.056	5.6E-4	5.3E-9	0	800	80	0.78	7.5E-6	0
Thorium	1.1	Th-232	1.8E-8	1.8E-8	1.7E-8	1.5E-8	9.5E-9	1.7E-10	1.7E-10	1.6E-10	1.5E-10	9.0E-11
Uranium	46,465	U-233	6.6E-8	9.4E-8	1.9E-7	4.4E-7	5.6E-6	6.3E-11	9.0E-11	1.8E-10	4.2E-10	5.3E-9
		U-235	1.8E-8	1.8E-8	1.8E-8	1.95-8	2.4E-8	1.7E-11	1.8E-11	1.8E-11	1.8E-11	2.3E-11
		U-236	2.7E-7	2.8E-7	2.8E-7	3.0E-7	5.0E-7	2.6E-10	2.6E-10	2.7E-10	2.9E-10	4.7E-10
		U-238	3.3E-7	3.3E-7	3.3E-7	3.3E-7	3.3E-7	3.2E-10	3.2E-10	3.2E-10	3.2E-10	3.1E-10
Neptunium	8,905	NP-237	7.1E-4	7.1E-4	7.1E-4	7.1E-4	7.1E-4	6.7E-7	6.7E-7	6.7E-7	6.7E-7	6.7E-7
Plutonium	703	Pu-238	0.088	0.056	0.023	2.3E-3	2.8E-21	8.4E-5	5.4E-5	2.2E-5	2.2E-6	2.7E-24
		Pu-239	0.030	0.030	0.032	0.034	0.052	2.9E-5	2.9E-5	3.0E-5	3.2E-5	5.0E-5
		Pu-240	0.11	0.11	0.10	0.094	0.029	1.0E-4	1.0E-4	9.8E-5	9.0E-5	2.8E-5
		Pu-241	2.9E-3	2.7E-3	2.4E-3	2.2E-3	8.5E-4	2.8E-7	2.6E-7	2.3E-7	2.1E-7	8.1E-8
		Pu-242	1.6E-4	1.6E-4	1.6E-4	1.5E-4	1.2E-4	1.5E-7	1.5E-7	1.5E-7	1.5E-7	1.2E-7
Americium	312	Am-241	2.8	2.7	2.5E	2.0	1.9E-3	2.7E-4	2.6E-4	2.4E-4	1.9E-4	1.8E-7
		Am-243	0.037	0.041	0.052	0.086	0.20	3.5E-6	4.0E-6	5.0E-6	8.2E-6	1.9E-5
Curium	3.7	Cm-244	0.66	0.015	7.1E-6	2.9E-13	5.4E-13	6.3E-4	1.4E-5	6.8E-9	3.5E-17	0.0

Note: The volume of brine is 0.92 m^3 made available by brine thermal migration with a threshold thermal gradient.

(a) Various other solubility data exist, some with higher and some with lower values for various nuclides. These other data may be no more or no less applicable to this preliminary analysis. More specifically carbon solubility data could be controlled by kinetics and not by equilibrium conditions.
(b) Values at 300 years.
(c) EPA,1985a.
(d) This element is not in the CHLW package. It would be separated in the fuel reprocessing plant and stored separately.

strontium, the expected gross volume of brine saturated with the element limits the radionuclide discharges to small fractions of the EPA limit. These fractions would be even lower if credit were taken for the fact that not all of the packages in a repository will fail simultaneously.

Except for cesium-137, the volume of saturated brine to dissolve enough radioactivity to reach the individual nuclide EPA limit ranges from 4.8 cubic meters (170 cubic feet) for strontium-90 to over 820 billion cubic meters (29 trillion cubic yards) for uranium-233. These brine volumes are unattainable unless the brine migration model (Section 6.4.2.3.2) underestimates available brine.

The rate of supply of brine to the package surface limits the rate of release of radionuclides from the package under expected conditions. If it is conservatively assumed that the brine flow rate without a thermal gradient threshold becomes saturated in the chemical elements contained in the waste as it reaches the package, an upper bound on any radionuclide release rate can be computed by multiplying the brine inflow rate by the solubility of the chemical element. Then the release rate from the package can be compared with the NRC 10 CFR Part 60 release rate limits for the engineered subsystem. If the package releases were to satisfy the 10 CFR Part 60 limits and the EPA standards, no requirements for retardation or prevention of release need be placed on other repository components.

The results of such calculations for the 10 CFR Part 60 limits are presented in Table 6-12 for CHLW and in Table 6-13 for the SFPWR package at the NRC-mandated minimum package lifetime of 300 years and for other times of interest. Including both packages at 300 years, the expected maximum release rates, even with the omission of many retarding factors, are below the NRC limit of 10^{-5} per year of the nuclide inventory at 1,000 years for all radionuclides except strontium-90, iodine-129, cesium-135, cesium-137, and curium-244. An alternate limit given in 10 CFR Part 60 may be applied to these nuclides. This limit, 0.1 percent of 10^{-5}, i.e., 10^{-8}, of the total 1,000 year activity in the package, is generally met by short-lived nuclides or those present originally in extremely small quantities. In these calculations, strontium-90 and curium-244 meet the alternate limit. Thus, iodine-129, cesium-135, and cesium-137 need constraints other than just a 300-year package to meet the 10 CFR Part 60 limits. For example, the alternate limit could be met for cesium-137 with additional decay of about 530 years for both SFPWR and CHLW. Half-lives of iodine-129 (15.9 million years) and cesium-135 (2.3 million years) are too long for demonstrable package lives to contain. However, the total inventory of cesium-135 and iodine-129 could be released into the accessible environment without violating 40 CFR Part 191 EPA standards.

If the waste form leach fraction is less than about 0.0013 per year, cesium-135 and iodine-129 would meet the alternate limit even with a 300-year package for either waste form. An interim performance specification for waste forms of 10^{-4} fractional release per year has been published (ONWI, 1983, ONWI-462, p. 11). If this specification were used with cesium-137, the package would only have to last about 130 more years than the minimum requirement of 300 for it to meet the 10 CFR Part 60 engineered subsystem alternative release limit.

The results described in this section assume package failure. The expected condition does not indicate package failure. Thus, these calculations demonstrate redundancy in that even if the package fails, limited solubility and quantities of brine limit the radionuclide release from the engineered subsystem. Other factors, as discussed but not specifically included in this preliminary analysis, also limit radionuclide release.

Summary of Performance of Engineered Barriers. There will be no radionuclide release under expected conditions from either CHLW or SFPWR packages because the package will not fail under expected corrosion conditions. If the package should fail, e.g., from human intrusion, the solubilities of the radionuclide elements in the expected total volume of thermally migrated brine (even without the expected volume reduction due to chemical reaction with overpack steel) will limit the radionuclide release from the package to within individual nuclide EPA limits prorated per package, except for cesium-137. It is recognized that the site limit consists of the sum of ratios for all nuclides. However, examination of individual

Table 6-33. Davis Canyon SFPWR Package. Comparison of Solubility and Maximum Brine Volume Limited Release at a Failed Waste Package Boundary with EPA Discharge Limits to the Accessible Environment

Element	Solubility,[a] grams/m^3	Package Inventory,[b] grams	Dissolved in Brine, grams	Nuclide	EPA Limit,[c] Curies per 1,000 MTHM	Ratio of Radioactivity[b] in Brine to EPA Limit	Total Volume of Saturated Brine to Reach EPA Limit, m^3
Carbon	0.06	833	0.026	C-14	100	0.47E-3	940
Selenium	0.001	279	4.4E-4	Se-79	1,000	0.64E-6	6.9E+5
Strontium	0.8	1,747	0.35	Sr-90	100	0.091	4.8
Technetium	0.001	3,812	4.4E-4	Tc-99	10,000	0.15E-6	2.9E+6
Tin	0.0001	19,216	4.4E-5	Sn-126	1,000	0.18E-8	2.5E+8
Iodine	600,000	1,157	1,157	I-129	100	0.31	Not saturated
Cesium	600,000	7,069	7,069	Cs-135	1,000	0.34	Not saturated
				Cs-137	1,000	80 (meets limit by decay at 490 years)	
Thorium	0.001	1.19	4.4E-4	Th-232	10	0.13E-9	3.4E+9
Uranium	0.001	4,774,600	4.4E-04	U-233	100	0.54E-12	8.2E+11
				U-235	100	0.16E-10	2.7E+10
				U-236	100	0.24E-09	1.8E+09
				U-238	100	0.29E-09	1.5E+09
Neptunium	0.001	4,276	4.4E-4	Np-237	100	0.62E-6	7.1E+5
Plutonium	0.001	38,380	4.4E-4	Pu-238	100	0.25E-4	1.8E+4
				Pu-239	100	0.36E-4	1.2E+4
				Pu-240	100	0.59E-4	7.5E+3
				Pu-241	1,000	0.18E-7	2.5E+7
				Pu-242	100	0.19E-6	2.3E+6
Americium	0.0001	4,301	4.4E-5	Am-241	100	0.27E-3	1.6E+3
				Am-243	100	0.16E-5	2.7E+5
Curium	0.001	4.4	4.4E-4	Cm-244	100	0.13E-4	3.4E+4

Table 6-33. Davis Canyon SFPWR Package. Comparison of Solubility and Maximum Brine Volume Limited Release at a Failed Waste Package Boundary with EPA Discharge Limits to the Accessible Environment

	10,000 year Inventory grams	Nuclide	Specific Activity, Ci/g					Ratio of Radioactivity in Brine to EPA Limit				
			200	300	500	1,000	10,000	200	300	500	1,000	10,000
Carbon	166.700	C-14	9.0E-3	8.9E-3	8.7E-3	8.2E-3	2.7E-3	4.8E-4	4.7E-4	4.6E-4	4.3E-4	1.5E-4
Selenium	55.270	Se-79	7.2E-3	7.2E-3	7.2E-3	7.2E-3	6.6E-3	6.4E-7	6.4E-7	6.4E-7	6.3E-7	5.8E-7
Strontium	347.800	Sr-90	1.4	0.13	1.1E-3	7.5E-9	0.0	0.98	9.1E-2	7.8E-4	5.3E-9	0.0
Technetium	740.300	Tc-99	1.7E-2	1.7E-2	1.7E-02	1.7E-7	1.7E-7	1.5E-7	1.5E-7	1.5E-7	1.5E-7	1.5E-7
Tin	3849.000	Sn-126	2.0E-4	2.0E-4	2.0E-4	2.0E-4	1.9E-4	1.8E-9	1.8E-9	1.8E-9	1.7E-9	1.6E-9
Iodine	231.800	I-129	1.3E-4	1.3E-4	1.3E-4	1.3E-4	1.3E-4	0.31	0.31	0.31	0.31	0.31
Cesium	1409.000	Cs-135	2.4E-4	2.4E-4	2.4E-4	2.4E-4	2.4E-4	0.33	0.33	0.34	0.34	0.34
		Cs-137	0.56	5.6E-2	5.6E-4	5.3E-9	0.0	8.0E+2	79.0	0.78	7.5E-6	0.0
Thorium	9.923	Th-232	1.5E-0	1.5E-8	1.5E-8	1.5E-8	1.5E-8	1.4E-10	1.3E-10	1.2E-10	1.2E-10	1.4E-10
Uranium	% 959500	U-233	4.1E-10	6.1E-10	1.3E-9	3.4E-9	5.0E-8	3.6E-13	5.4E-13	1.2E-12	3.0E-12	4.4E-11
		U-235	1.8E-8	1.8E-8	1.8E-8	1.9E-8	2.1E-8	1.6E-11	1.6E-11	1.6E-11	1.6E-11	1.9E-11
		U-236	2.7E-7	2.7E-7	2.7E-7	2.8E-7	3.7E-7	2.4E-10	2.4E-10	2.4E-10	2.5E-10	3.2E-10
		U-238	3.3E-7	3.3E-7	3.3E-7	3.3E-7	3.3E-7	2.9E-10	2.9E-10	2.9E-10	2.9E-10	2.9E-10
Neptunium	1652.000	Np-237	7.1E-4	7.1E-4	7.1E-4	7.1E-4	7.1E-4	6.2E-7	6.2E-7	6.2E-7	6.2E-7	6.2E-7
Plutonium	5049.000	Pu-238	6.1E-2	2.8E-2	5.9E-3	1.3E-4	4.1E-23	5.4E-5	2.5E-5	5.2E-6	1.2E-7	3.6E-26
		Pu-239	4.0E-2	4.0E-2	4.1E-2	4.1E-2	4.7E-2	3.5E-5	3.6E-5	3.6E-5	3.6E-5	4.1E-5
		Pu-240	6.7E-2	6.6E-2	6.4E-2	3.6E-2	5.9E-5	5.9E-5	5.9E-5	5.8E-5	5.6E-5	3.2E-5
		Pu-242	2.2E-4	2.2E-4	2.2E-4	2.3E-4	3.3E-4	1.9E-7	1.9E-7	2.0E-7	2.0E-7	2.9E-7
Americium	32.380	Am-241	3.2	3.1	3.0	2.8	1.9E-3	2.8E-4	2.7E-4	2.7E-4	2.3E-4	1.7E-4
		Am-243	1.6E-2	1.9E-2	2.4E-2	4.6E-2	0.20	1.4E-6	1.6E-6	2.2E-6	4.0E-6	1.8E-5
Curium	0.381	Cm-244	0.66	1.5E-2	7.1E-6	3.6E-14	0.0	5.8E-4	1.3E-5	6.3E-9	3.2E-17	0.0

Note: The volume of brine is 0.44 m^3 made available by brine thermal migration with a threshold thermal gradient.

(a) Various other solubility data exists, some with higher and some with lower values for various nuclides. These other data may be no more or no less applicable for this preliminary analysis. More specifically, carbon solubility data could be controlled by kinetics and not by equilibrium conditions.

(b) Maximum value during the period 300 years to 10,000 years.

(c) EPA, 1985a.

ratios provides a perspective toward actions which would help to meet these standards. Cesium-137 will decay radioactively to meet the EPA limit at only 490 years, even though 830 years are required for meeting NRC limits. Since either of these durations is much less time than the travel time to the accessible environment boundary along any realistic pathway, cesium-137 is of little significance in meeting EPA criteria. Furthermore, even brine volume saturation-limited releases are probably not physically attainable because of the omission in the calculations of many retarding factors.

The 10 CFR Part 60 standards are met if the expected conditions prevail (i.e., that the waste package remains intact for a very long time). Even if a package fails, the brine would have been consumed up to that time and other factors retard releases; thus waste form releases would be limited. These bounding calculations, assuming no thermal gradient threshold for brine migration, no brine consumed by chemical reaction (after package failure), and package failure, indicate that cesium-137 is the limiting nuclide and, ignoring factors other than a waste form specification of 10^{-4}, that the package would have to last about 430 years to meet 10 CFR Part 60.

6.4.2.3.5 Geologic Subsystem Performance. The performance of the geologic subsystem for a salt repository is reflected primarily by considerations of the following: (1) the migration of brine toward the heat sources provided by the waste packages, (2) the possible mobility of brine by diffusion away from waste packages after package failure with dissolved radionuclides, and (3) the flow of ground water toward the accessible environment with dissolved radionuclides if radioactivity has been encountered by the ground water for any reason. The presence of a disturbed zone in which accelerated flow might occur is hypothesized by 10 CFR Part 60. The extent of the disturbed zone is estimated, and for the purposes of these analyses, any travel time required to transit the disturbed zone is not included. In addition, inadequate or faulty shaft seals might affect radionuclide transport. Seal performance will be discussed.

Brine migration toward heat sources was described in Section 6.4.2.3.2; brine movement away from the waste by a diffusion-like process and the possibility of ground-water flow in intact salt, and through or around seals, is described in this section. In addition, ground-water flow in nearby aquifers is described in this section.

Estimation of the Extent of the Disturbed Zone. The disturbed zone is defined as, "that portion of the controlled area, excluding shafts, whose physical or chemical properties are predicted to change as a result of underground facility construction or heat generated by the emplaced radioactive waste such that the resultant change of properties could have a significant effect on the performance of the geologic repository" (DOE General Guidelines for Recommendation of Sites for Nuclear Waste Repositories, May 14, 1984, p. 3). The definition is consistent with that given in 10 CFR Part 60; however, in order to be useful, the dimensions of the disturbed zone must be quantified. An estimate of these dimensions is given in Appendix 6-A.

Several processes and phenomena that could affect the rock surrounding the repository are discussed in Appendix 6-A. Results show the following estimates for disturbed zone size:

Disturbance	Range
Mechanical	Less than 15 meters (49 feet)
Chemical	Probably insignificant
Thermomechanical	Disturbance tends to close openings and heal host rock fractures
Thermalhydrologic	About 10 meters (33 feet)
Radiation	Less than 1 meter (3.3 feet)

On the basis of this discussion, the disturbed zone from all disturbances (excluding thermal) should not exceed 15 meters (49 feet). Mechanical disturbance is a function of the mining and rock parameters. Therefore, when site-specific data are obtained at the repository horizon, mine design and field measurements will determine the amount and impact of the "mechanical" contribution to the disturbed zone.

Brine Mobility Away From Waste. McNulty et al. (1985) give the equations that govern the transport of brine away from the waste package under a diffusion-like mechanism. Under expected repository conditions (Section 6.4.2.3.2), brine migration caused by temperature-dependent solubility will first drive brine towards the waste package. However, these diffusion analyses can ignore the relatively short times required for brine accumulation around the waste package. The analyses assume that all temperature gradients have dissipated and, consequently, the thermally driven brine transport has already occurred. The data used in the analyses consist of an empirical diffusion coefficient and total expected brine volumes accumulated around the waste package (McCauley and Raines, 1985).

Knauth (1982) gives data for the distribution of water in salt surrounding a brine pocket associated with a sediment inclusion in a salt mine in Weeks Island dome. Knauth used the vacuum volatilization technique of Knauth and Kumar (1981) to measure the water content of salt specimens sampled at various distances from the brine pocket. An empirical brine diffusion coefficient of 4.9×10^{-12} square meter per second (1.5×10^{-4} square meter per year) is derived from these data when a diffusion-like process is assumed and the age of isolation of the sediment is assumed to be 75 million years (McNulty et al., 1985). If the sediment were included at the time of deposition of the salt, the age is greater than 75 million years. However, using lower ages is conservative, because it will maximize the diffusion coefficient.

It is well known that the mean square of the distance that a particle travels by diffusion from a point source is equal to six times the product of the diffusion coefficient and time. Thus, the mean distance traveled with diffusion coefficient, D, in time, t, is equal to the square root of 6Dt. Thus, with $D = 1.5 \times 10^{-4}$ square meter per year, distances traveled are about 3, 10, and 30 meters (9.8, 32.8, and 98 feet) for 10,000, 100,000, and 1 million years, respectively. An additional distance of 15 meters (49 feet) may be added to allow for the disturbed zone. These results indicate that brine moving away from the waste package area by this mechanism will be contained within the host rock (Cycle 6 of Paradox salt) for more than 100,000 years. This theory is also used to estimate the transport of radioactivity in the host rock in Section 6.4.2.4.

Possible Darcy Flow in Host Rock. Ground-water movement through host rock in response to a hydraulic gradient is one of the major factors of interest in defining the expected long-term (postclosure) performance of a repository. Such a movement of ground water is, in part, controlled by the apparent bulk permeability of the host rock and is normally calculated by Darcy flow theory. Although there is little question that salt has void spaces (Lorenz et al., 1981); whether these voids are interconnected is uncertain. The behavior of salt under confining pressures, such as exist at repository depth, tends to close passageways at crystal interfaces. Thus, it is not certain if Darcy flow occurs in intact salt. The following paragraphs assume that it does.

Experimental determination of rock salt permeabilities has proven problematic. In situ measurements have yielded permeability estimates for salt of 10^{-2} millidarcys to less than 10^{-4} millidarcys (below measurement limit) (Acres American, Inc., 1979, Tables 4 and 5). These measurements were taken from salt pillars within mining excavations. The higher values were measured near the pillar wall and the lower values were measured deeper into the pillar where the salt was less disturbed. Laboratory permeability tests on rock salt indicate that care must be taken in procedure and interpretation because cores are easily damaged and the intercrystalline boundaries relax as the sample is removed from the in situ stress field (Tien et al., 1983, NUREG/CR-3129, p. 209; Baar, 1977).

Hydraulic properties within the Paradox Formation are highly variable depending on what lithology is being tested (e.g., dolomite, shale, anhydrite, or salt). Given that the regional values have been generated by the oil industry, and that the tested horizons would

represent the most porous zones (as identified on the geophysical logs), it is not surprising that these reported values are relatively high. Values ranging between 550 and 0.1 millidarcy are reported in Appendix A-6 of the geologic characterization report (WCC, 1982, ONWI-290, Vol. V). Drill-stem tests conducted in GD-1 indicate a range of between 7.2 and 0.21 millidarcy for the tested interbeds.

The very low transmissivity of intact salt makes direct observation of fluid movement difficult. This difficulty results in uncertainty in modeling fluid movement through salt. To account for this uncertainty, a salt permeability range of 10^{-7} to 10^{-2} millidarcy (8.3×10^{-11} to 8.3×10^{-6} meter per day) was used to evaluate the sensitivity of ground-water travel times through the host salt to permeability. Darcian flow (porous media) was assumed. Salt permeability of 10^{-2} millidarcy (8.3×10^{-6} meter per day) in the vertical direction is considered to be larger than the upper bound for this parameter; the lower bound is considered to be zero. Thus, the range of salt permeabilities used is considered to be conservative with respect to ground-water travel times in the host salt.

Performance of Shaft Seals. Preliminary analyses (INTERA, 1984, ONWI-503, Table ES-4; Gureghian et al., 1983, ONWI-494, p. 41) show that ground-water flow around and through the shaft-seal system will probably be very small. Thus, the shaft-seal system will likely not contribute significant quantities of water to the repository. Final Rule 10 CFR 60.134 states:

> Seals for shafts and boreholes shall be designed so that following permanent closure they do not become pathways that compromise the geologic repository's ability to meet the performance objectives for the period following permanent closure.

The DOE will demonstrate that the seal design will function as intended before construction authorization is granted (NRC, 1983, 10 CFR 60.31). The design process will be conducted in concert with performance assessments until a design is achieved that is predicted to function as required. The shaft-seal system will use methods of construction and materials selected to reduce preferential water-flow pathways to meet the requirements of 10 CFR 60.134 (Kelsall et al., 1982, ONWI-405; Burns et al., 1982; Christensen and Hunter, 1981). To cause an impact, an unlikely failure must occur within 70 years to provide sufficient ground-water flow, prior to expected creep closure of the backfilled repository, to fill the voids in the crushed salt backfill (INTERA, 1985 BMI/ONWI-553).

Calculations (Gureghian et al., 1983, ONWI-494, pp. 20-31) for a hypothetical repository in the Paradox Basin, using generic properties, show that the expected penetration time for ground water to reach repository level is at least tens of thousands of years. The order of magnitude of this result is expected to be applicable for a repository at any salt site under consideration. Thus, the likelihood of any ground water reaching the repository storage rooms is reduced. Given the planned sequential emplacement of waste canisters, and backfilling of storage rooms 1 year after waste has been emplaced (SCC, 1984, pp. 5-15), creep closure of the repository rooms will be under way before engineered closure of the repository. Placement of bulkheads in the repository will provide a temporary seal until creep closure is complete.

Thus, a successful seal system will not impact the expected performance of a repository in salt. This fact must be conclusively demonstrated during site characterization and other future activities.

Pre-Waste-Emplacement Ground-Water Flow Paths and Travel Times. The geologic and hydrologic conditions in the region around the candidate area and the Davis Canyon site are presented in Sections 3.2 and 3.3. Several conceptual models of the regional ground-water flow system within the Paradox Basin have been developed (INTERA, 1984, ONWI-503; Andrews et al., 1984; Dunbar and Thackston, 1985, BMI/ONWI-571). The regional ground-water model analyses are used to evaluate the effects of long-term climatic changes (discussed later in this section) and to define the ranges of hydraulic gradients for local ground-water flow modeling to estimate pre-waste-emplacement ground-water travel times.

Although the models developed to date use different conceptualizations of the hydrogeologic setting, the following general conclusions reached by these models are consistent:

(1) The regional vertical hydraulic gradient between the upper and lower hydrostratigraphic units is generally downward.

(2) The horizontal hydraulic gradients in the upper hydrostratigraphic unit is about 0.0014 and ranges from 0.0023 to 0.0045 in the lower hydrostratigraphic unit (INTERA, 1984, ONWI-503; Andrews et al., 1984, Table 3-3).

(3) The ground-water discharge area for the lower hydrostratigraphic unit is uncertain and depends on the vertical permeability across the evaporite aquitard in the middle hydrostratigraphic unit.

(4) The anticipated ground-water travel times from possible repository sites to eventual ground-water discharge locations are extremely long. The principal differences in the travel-time estimates are due to the uncertainty in the permeability of salt and other media of low permeability in the middle hydrostratigraphic unit.

Defining the likely ground-water flow mechanism is an important consideration in the evaluation of ground-water travel paths and travel times. In order to address this issue, a panel of hydrologists was convened by the Department of Energy (DOE) (ONWI, 1985) specifically to evaluate ground-water flow in fractures of the Palo Duro Basin Texas, and also to make evaluations on all sites in other regions. The following are their broad recommendations regarding pre-waste-emplacement ground-water travel time analyses for the bedded sites:

(1) Porous-media flow should be considered as the most probable flow path through the sedimentary strata. However, because of the uncertainties, the porous flow paths and resultant travel time should be stochastically evaluated using realistic distributions for all the key parameters.

(2) A low-probability fracture-controlled pathway should also be considered. Some analyses should be carried out assuming a vertical lineament feature penetrating the sedimentary stratigraphic sequence in the vicinity of the repository which provides higher permeability and lower effective porosity in the more brittle rock units only, and porous-media flow through the salts.

(3) Fracture-, fissure-, or fault-generated hydrologic pathways through the halite-rich units should not be considered due to lack of credible evidence for their existence at this stage.

(4) Similar travel-time calculations and analyses could be made for the Paradox Basin sites in Utah which have a similar geologic setting.

(5) Site characterization plans should include some emphasis on characterizing the location, extent, and hydraulic significance of both lineament features on the surface and structural features extending from the basement.

These recommendations have been followed in the local ground-water flow modeling conducted to evaluate pre-waste-emplacement travel paths, travel times, and their uncertainty.

Small-scale lithologic heterogeneities control the ground-water travel path from the edge of the disturbed zone to the accessible environment. In a stratified geologic environment consisting of heterogeneous layers of differing lithologies (salts, anhydrite, dolomite,

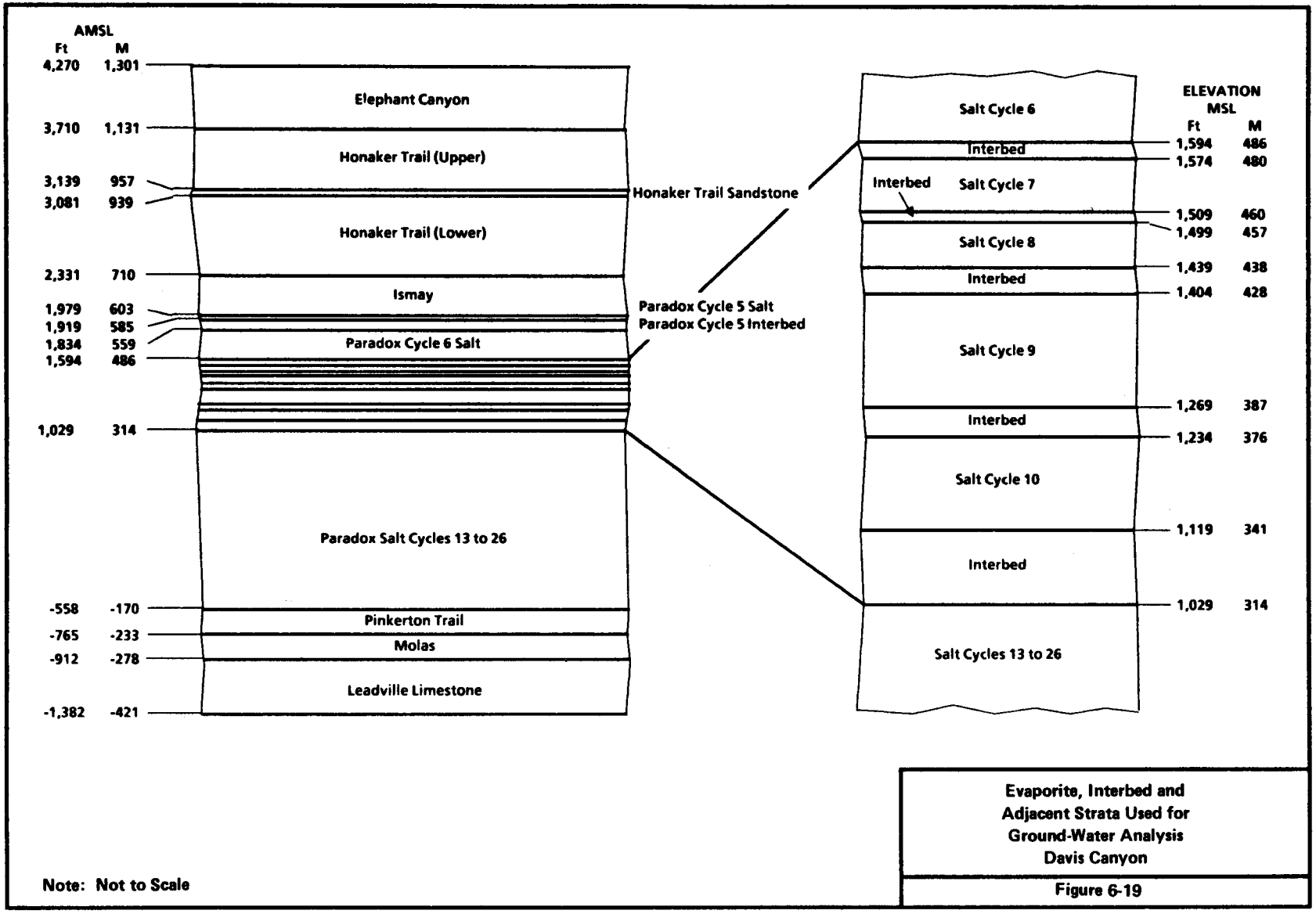
siltstone, etc.), the ground-water travel path to the regulatory accessible environment is a function of the permeability of the varying lithologies, the horizontal and vertical hydraulic gradients within each layer, and the thickness and continuity of each layer. Because all of these values are uncertain, the expected travel path and travel time along this path to the accessible environment are also uncertain. In order to quantify this uncertainty, a computer code, PTRACK (Thompson et al., 1985), has been developed to evaluate probability distributions of particle trajectories from given distributions of hydrogeologic parameters. PTRACK uses the Latin Hypercube Sampling technique (Iman and Shortencarier, 1984, NUREG/CR-3624) to sample from input distributions of uncertain parameters, and then to calculate trajectories and travel times from the edge of the disturbed zone to the accessible environment. PTRACK is designed to evaluate the impact of data uncertainties, not the uncertainties associated with the hydrologic conceptual model. The output from PTRACK consists of the statistics (mean and variance) of the travel time distributions, as well as graphic displays of the travel-path, travel-time histogram, and complementary distribution function.

The Davis Canyon site is modeled as having 21 horizontal layers (Figure 6-19) which represent differing lithologies (based on information from the Gibson Dome No. 1 well). Each layer is assigned a value for permeability, porosity, horizontal gradient, and total dissolved solids (TDS). These values are determined by sampling for each trial from parameter distributions. The vertical hydraulic gradient is computed using environmental heads (Lusczynski, 1961) which are determined from observed pressures in, at most, three horizontal layers. The use of environmental heads for calculating vertical hydraulic gradients takes into account the varying density of the fluids between the vertically separated pressure measurement points. The values for pressure and TDS used in the calculation of environmental head are also considered to have probability distributions. For the saline fluids which exist in a bedded salt environment, the TDS of the fluid is the most prominent (compared to temperature and pressure variations) parameter that controls the fluid density (Muller et al., 1981, SAND81-0557). PTRACK accounts for the TDS variations in each layer. The vertical gradient within each layer between any two environmental head elevations (except the top and bottom layers, which are considered to be aquifers with predominantly horizontal gradients) is computed assuming a uniform vertical flux across each layer. This vertical flux is not modified by the variable horizontal flux between different layers.

The relevant geohydrologic properties are assumed to be homogeneous within each layer for a given trial. This implies that each sampled parameter is constant over distances of several kilometers. If the horizontal correlation length of a given property is significantly less than several kilometers, the appropriate average property over that distance has a much tighter distribution (small variance) than the entire distribution of all observed values. Hence, using the entire distribution (as is done in PTRACK) creates a broader travel time distribution, i.e., an increased probability of very short and very long travel times, which is considered conservative from a performance assessment perspective.

Because of the well-stratified geologic environment that exists in the Paradox Basin in general and in the Davis Canyon site in particular, the observed geology at the Gibson Dome No. 1 well is used for local scale ground-water modeling to estimate travel-time distributions to the 1 kilometer (0.6 mile) accessible environment as defined in this report. The continuity and thickness of each layer are considered constant within the modeled region. The permeable sandstones within the Elephant Canyon Formation are considered to represent the uppermost aquifer of interest, while the Leadville Limestone represents the lowermost aquifer. The strata between the Leadville and Elephant Canyon Formations include 19 layers. The lithologies include salt (Salt Cycles 5, 6, 7, 8, 9, 10, and 13 through 26 of the Paradox Formation), dolomite/limestone/anhydrite/siltstone interbeds of the Paradox Formation, sandstone/siltstone (Elephant Canyon and permeable sandstones in the Honaker Trail), limestone (upper and lower Honaker Trail, Pinkerton Trail and Leadville), and shale (Molas).

To address uncertainties in hydrogeologic parameters (permeability, porosity, vertical pressure distribution, horizontal hydraulic gradients, and total dissolved solids) affecting



Note: Not to Scale

Evaporite, Interbed and Adjacent Strata Used for Ground-Water Analysis Davis Canyon

Figure 6-19

ground-water travel time estimates, a range of values for each parameter has been considered (Andrews et al., 1985) as described below. The ranges are described here by presenting one-chance-in-1,000 values which correspond to 3.1 standard deviations from the mean. These ranges are based on regional distributions and the uncertainty in the measurements conducted in the Gibson Dome No. 1 well. The stochastic analysis does not address uncertainties in the conceptual models. However, very conservative assumptions, which should cover these uncertainties, were used and the values given here should be conservative.

The pressures used in evaluating the vertical hydraulic gradients are based on observations made at Gibson Dome No. 1 by Thackston et al. (1984, ONWI-491, Table 3-12). The average equivalent freshwater head of the three Cedar Mesa and Elephant Canyon pressure measurements is 1,476 meters (4,843 feet), plus or minus 41 meters (135 feet). The average equivalent freshwater head in the Leadville Limestone is 1,341 meters (4,400 feet) plus or minus 46 meters (150 feet). These values have been converted to pressures at depth for input to PTRACK to estimate the environmental heads used for defining the vertical hydraulic gradient. The observed pressures within the low permeability strata of the lower portions of the Honaker Trail and the interbeds within the Paradox Formation are erratic, indicating the lack of hydraulic communication across the middle hydrostratigraphic unit. The observed pressure variability, if real, could imply downward or upward hydraulic gradients across the proposed host salt (Salt Cycle 6). In order to address both potential flow directions, the average equivalent freshwater head in the lower portion of the Honaker Trail (922 meters [3,025 feet] plus or minus 53 meters [175 feet]) and the Ismay section of the Paradox Formation (1,629 meters [5,346 feet], plus or minus 91 meters [300 feet]) have been used in separate analyses of likely travel paths and travel times (Andrews et al., 1985). These values have been converted to pressures at depth for input to PTRACK.

The permeability distributions used for each layer are based on either regional permeability distributions, laboratory and in situ tests conducted at Gibson Dome No. 1, or generic rock permeability ranges. The Leadville permeability distribution is based on the 89 observations displayed in Figures 3-59. The permeability distributions in the Pinkerton Trail, Molas, and Paradox interbeds are assumed to be log normally distributed with a range from 11.0 to 5.4×10^{-5} millidarcys. This corresponds to the maximum and minimum values observed in the short and long term hydrologic tests conducted in Gibson Dome No. 1 (Thackston et al., 1984, ONWI-491). The Paradox interbeds are assigned a range from 11.0 to 5.4×10^{-5} millidarcys in order to capture the questionable early time data of the short-term tests. The permeability distributions in the upper and lower Honaker Trail, the Honaker Trail sandstone beds, and the Elephant Canyon siltstones are all considered to be log normally distributed with ranges (generated from Gibson Dome No. 1 tests) of 0.24 to 2.4×10^{-5} millidarcys, 17.0 to 0.24 millidarcys and 7.3×10^{-3} to 7.8×10^{-4} millidarcys, respectively. The permeability range for the most permeable beds in the Elephant Canyon is from 87 to 25 millidarcies. The permeabilities of each salt layer were assumed to be log normally distributed with a range from 10^{-2} to 10^{-7} millidarcys. The maximum value of this range captures the maximum observed laboratory values conducted at in situ confining pressures and the maximum observed in situ values.

The porosity distributions used for each layer are generally based on laboratory core data present in Thackston et al. (1984, ONWI-491). The salt porosities have been inferred from resistivity logs in the Palo Duro Basin (Andrews et al., 1985). All porosities are assumed to be normally distributed. The porosity ranges used are defined below.

Formation	Porosity Range (%)
Elephant Canyon sandstone	5.2 - 12.5
Honaker Trail carbonate	1.3 - 5.4
Honaker Trail sandstone	10.0 - 15.5
Ismay	0.6 - 7.9
Paradox salt beds	0.3 - 1.64
Paradox interbeds, (Pinkerton Trail and Molas)	0.6 - 12.6
Leadville Limestone	11.2 - 15.

The generally accepted positive correlation between permeability and porosity has not been incorporated in the travel path and travel time analyses described below. Again, this is a conservative assumption from an expected performance perspective.

It is generally accepted that the Leadville Limestone is fractured (Thackston et al., 1984, ONWI-491; Section 3.3.2). To account for this in the travel-path and travel-time assessment, the matrix porosity distribution of the Leadville Limestone was reduced by a factor of 100, yielding a range of 0.11 to 0.15 percent for all trials. The other layers in the analyses of the expected travel path and travel time are not considered to be fractured or, if they are, the fractures have been healed. If the other layers do contain water-bearing fractures, then travel times would be less than the calculated values.

The ground water within all evaporite and interbed layers in the vicinity of the Davis Canyon site is considered to be salt saturated with a TDS content of 350,000 milligrams per liter. The TDS content of the Leadville Limestone is considered to have a normal distribution with a range from 70,633 to 88,633 milligrams per liter. The total dissolved solids (TDS) of ground water in the Pinkerton Trail and Molas is considered to be equivalent to that observed in the Leadville Limestone. The TDS content of the Honaker Trail water is also assumed to have a normal distribution with a range from 85,000 to 155,000 milligrams per liter, based on observations at Gibson Dome No. 1. The Elephant Canyon has a TDS content of about 6,400 milligrams per liter $\pm$ 1,000 milligrams per liter, while the Cedar Mesa ground water is generally fresh (i.e., less than 1,000 milligrams per liter).

The horizontal hydraulic gradient used in the analyses of ground-water travel paths and travel times is considered to vary (Andrews et al., 1985). Triangular distributions have been used for each layer as defined below.

	Horizontal Hydraulic Gradient		
	Minimum	Mode	Maximum
Elephant Canyon	.013	.014	.017
Honaker Trail (upper)	.013	.019	.020
Honaker Trail (lower)	.033	.038	.040
Paradox (all salts and interbeds), Pinkerton Trail and Molas	.012	.014	.033
Leadville Limestone	.0045	.0058	.0065

The above distributions have been sampled for 1,000 realizations (representations of the ground-water system by selecting combinations of geohydrologic parameters) for the travel-path and travel-time analyses for the distance from the disturbed zone to the accessible environment (Andrews et al., 1985). If the disturbed zone is assumed to extend to 15 meters beyond the limits of the repository excavation, some of the ground-water travel path to the accessible environment would likely be within Paradox Salt Cycle 6 (the host rock) before reaching the overlying or underlying interbed. Given the uncertainty in defining the extent of the disturbed zone, the travel paths and travel times presented below conservatively consider the disturbed zone to extend outside the Cycle 6 host salt to the base of the overlying carbonate interbed and the top of the underlying anhydrite interbed. Therefore, travel times in the host salt are not added in the total ground-water travel time estimates to the 1-kilometer (0.6-mile) accessible environment. If travel times in the host salt are considered, the overall travel time to the accessible environment is increased 10^4 to 10^5 years (Andrews et al., 1985). In addition, to reflect the uncertainty in the observed pressures in the GD-1 well within the Ismay and the lower Honaker Trail, two sets of analyses were conducted, one with the Ismay observed pressures, and the other with the lower Honaker Trail pressures to address the potential range in flow directions.

PTRACK has been used to evaluate the most likely travel paths and travel times in porous media and the less likely fracture-controlled travel path and travel times (discussed later). The Latin Hypercube sampling technique was used to define 1,000 realizations of the local ground-water flow system for porous-media flow analysis. The results of these analyses are

described below in the form of travel-time histograms and cumulative probability distributions for travel times. In addition, tables showing the probability of a particle exiting a given geologic layer to the 1-kilometer (0.6-mile) accessible environment (as defined in this report) are also presented. As EPA regulations state that the controlled area should not encompass more than 100 square kilometers (39 square miles) and its boundary should not extend over 5 kilometers (3 square miles) in any one direction from the outer boundary of the repository (40 CFR 191.12[g], Subpart B) it is possible for the DOE to redefine the controlled area following site characterization. Sensitivity analyses for distances of 1, 2, 3, 4 and 5 kilometers have been conducted as described at the end of this section to assess the effect on travel time to the accessible environment should the controlled area be adjusted.

Representative travel paths to the 1-kilometer (0.6-mile) accessible environment, generated by PTRACK and assuming applied pressures in the Ismay, are downward. If the Honaker Trail pressure is used in the analysis, all paths are upward. Uncertainty in the flow direction is directly related to the uncertainty in the hydrologic significance of the observed pressures within the low permeability strata at Gibson Dome No. 1. While the overall gradient between the upper and lower hydrostratigraphic units is downward, either local upward or downward gradients may be present within the salt section.

The distribution of travel paths is best represented by examining the layer from which each particle exits to the accessible environment. The relative fraction of particles which exit from different layers, considering both the Ismay and Honaker Trail pressures, is presented in Table 6-34. When flow is downward, interbeds in the Paradox Formation are the preferred exit layers. When flow is upward, the lower Honaker Trail is the preferred exit layer (in fact, particles cannot travel farther up the section due to the convergent flow).

The travel-time histograms and complementary cumulative distribution functions for the differing mid-point pressures (Honaker Trail and Ismay), and distances to the accessible environment are illustrated in Figures 6-20 and 6-21. As expected, the travel-time distribution is quite broad due to the broad ranges in hydrologic properties. While the travel path (upward or downward) depends on the mid-point pressure used in the analysis, the travel time distributions are quite similar.

From a performance perspective, the probability of a travel time being less than 1,000 years or 10,000 years is important. As summarized in Table 6-35, the probability of not meeting the 1,000 year travel time criteria, even given the conservative assumptions enumerated above, is 0.003. That is, there are three estimated travel times less than 1,000 years in 1,000 trials. The probability of not meeting the 10,000 year criteria is 0.045. The mean travel time is considered to describe the expected condition while the median travel time is also a measure of central tendency and is a more conservative value. The uncertainly in this value is depicted in the travel-time histograms (Figure 6-20).

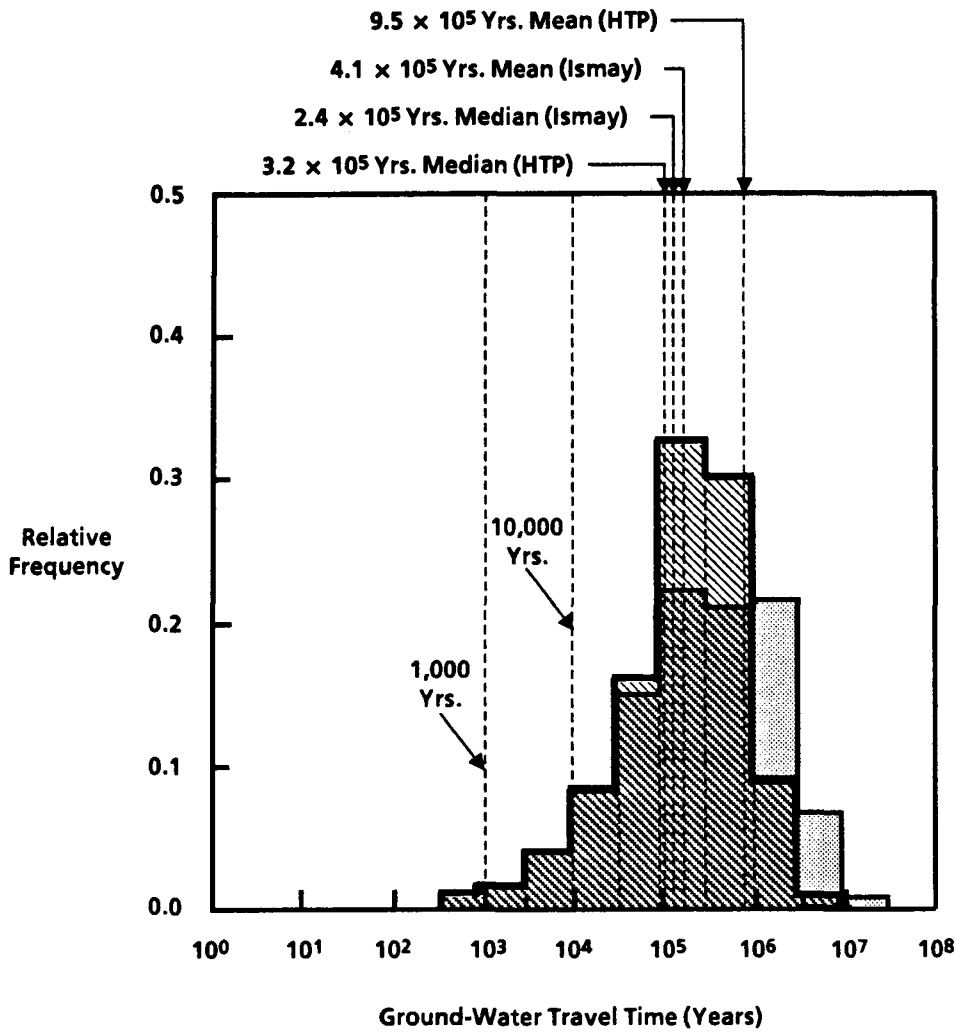
The expected condition for ground-water flow in the vicinity of the Davis Canyon site is porous media flow as was assumed in calculating the travel times and probabilities given above. Fracture-controlled pathways near the site are considered unlikely. Nonetheless, as a result of considering peer review panel recommendations, analyses were conducted to address unlikely pathways. The analyses discussed below are primarily to evaluate and provide an understanding of the potential effects of fracture-controlled pathways if such pathways are found during site characterization.

To evaluate the effects of potential fracture-controlled pathways on the travel-time distribution, the following assumptions were included in the additional analyses using the PTRACK model: (1) the faults delineated on maps of McCleary et al. (1983, ONWI-485) penetrate the sedimentary sequence, and (2) these features provide for higher permeability and lower effective porosities in the more brittle rock units. No data on the probability of fracture zones intersecting likely particle travel paths are available. Using the spatial distribution of surficial features (McCleary et al., 1983, ONWI-485), 1,000 random repository (2-kilometer [1.2-mile] effective radius) centroid locations were located to evaluate the minimum distance to a potential fracture zone in the expected particle direction down gradient from the repository (Andrews et al., 1985). This information is used to define the distance a particle moves

Table 6-34. Particle Exit Layer Distributions From 1,000 Realizations of Davis Canyon Local Ground-Water System, 1-kilometer Accessible Environment (Likely porous media flow)

	Distribution Based on Ismay Pressure	Distribution Based on Honaker Trail Pressure
Elephant Canyon		
Honaker Trail (upper)		
Honaker Trail sandstone		
Honaker Trail (lower)		0.158
Ismay		0.188
Paradox Salt Cycle 5		
Paradox Salt Cycle 5 interbed		0.654
Paradox Salt Cycle 6		
Paradox Salt Cycle 6 interbed	0.331	
Paradox Salt Cycle 7	0.003	
Paradox Salt Cycle 7 interbed	0.165	
Paradox Salt Cycle 8	0.002	
Paradox Salt Cycle 8 interbed	0.226	
Paradox Salt Cycle 9	0.003	
Paradox Salt Cycle 9 interbed	0.105	
Paradox Salt Cycle 10	0.002	
Paradox Salt Cycle 10 interbed	0.088	
Paradox Salt Cycles 13-26	0.013	
Pinkerton Trail	0.039	
Molas	0.015	
Leadville Limestone	0.008	
	1.000	1.000

Note: Representatives of ground-water system by selecting combinations of geohydrologic parameters.



Explanation

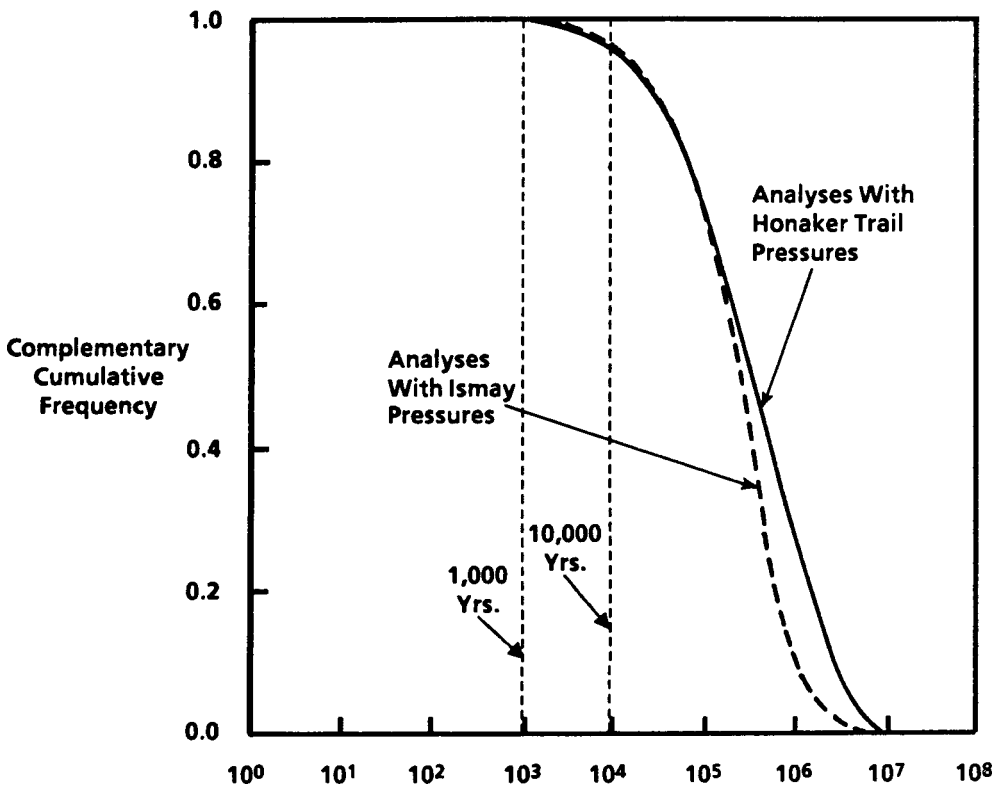
Analysis With Honaker Trail Pressure
Mean (yrs.) = 9.5×10^5
Median (yrs.) = 3.2×10^5

Analysis With Ismay Pressure
Mean (yrs.) = 4.1×10^5
Median (yrs.) = 2.4×10^5

Note: Pre-waste emplacement ground-water travel times from disturbed zone to 1 km accessible environment, based on 1,000 combinations of geohydrologic parameters.

Relative Frequency of Ground-Water Travel Times for Likely Conditions of Porous Media Flow Davis Canyon

Figure 6-20



Analysis With Ismay Pressure		Analysis With Honaker Trail Pressure	
95th Percentile	= 1.1×10^4	95th Percentile	= 1.0×10^4
50th Percentile	= 2.4×10^5	50th Percentile	= 3.2×10^5
5th Percentile	= 1.4×10^6	5th Percentile	= 3.8×10^6

Note: Pre-waste emplacement ground-water travel times from disturbed zone to 1 km accessible environment, based on 1,000 combinations of geohydrologic parameters.

Complementary Cumulative Frequency of Ground-Water Travel Times for Likely Conditions of Porous Media Davis Canyon

Figure 6-21

Table 6-35. Summary of Travel-Time Results with 1-Kilometer Accessible Environment and Porous Flow (likely conditions)

	Probability of Travel Time		Travel Time,
	1,000 years	10,000 years	Median (Years)
Ismay Pressure	0.003	0.045	2.4×10^5
Honaker Trail Pressures	0.003	0.045	3.2×10^5

Note: Representatives of ground-water system by selecting combinations of geohydrologic parameters. Assumes open and continuous fractures.

before intersecting a fracture zone. Within the fracture zone, the ground-water flux is considered to be unchanged and velocity increases by a factor of 100. When a particle intersects a fracture zone within a brittle unit, the particle is assumed to stay within the fracture zone for the remaining distance to the accessible environment.

The distribution of particle exit layers for unlikely pathways is given in Table 6-36. The calculated travel-time distributions are illustrated in Figures 6-22 and 6-23. With the Ismay and Honaker Trail pressures, the probabilities of unlikely pathways travel times being less than 1,000 years are 0.074 and 0.075 respectively, and the probability for being less than 10,000 years is 0.214 for both cases (Table 6-37).

40 CFR 191 limits the controlled area to a maximum of 100 square kilometers (39 square miles). Repository location after site characterization will identify distance to the controlled area boundary (which will be considered the accessible environment). As the distance to the accessible environment may differ from 1 kilometer (0.6 mile) following site characterization, analyses have been performed with accessible environment distances of 1, 2, 3, 4, and 5 kilometers (0.6, 1.2, 1.9, 2.5 and 3.1 miles) (Table 6-38). These sensitivity analyses provide an understanding of probabilities of ground-water travel times with variable distances to the controlled area boundary.

Numerous conservative assumptions have been included in the travel-time analyses for likely and unlikely pathways. These assumptions tend to either broaden the range of travel times (raise the high values and lower the low values) or shift the entire distribution to lesser travel-time values. The extreme ranges (lower and higher) of the travel-time estimates should be considered in the proper perspective of the following basic assumptions (Andrews et al., 1985):

1. The accessible environment is at 1 kilometer (0.6 mile) from the disturbed zone.

2. The disturbed zone extends into the overlying and underlying brittle interbeds (i.e., taking no credit for travel time in the host salt unit).

3. There is a lack of correlation between input parameters (such as permeability and porosity).

4. There is a lack of spatial correlation of hydrologic parameters.

5. Resistivity logs are used to define in situ porosities.

6. Fracture-controlled pathways are parallel to ground-water flow path.

7. Particles entering a fracture stay in the fracture-controlled pathway until they reach the accessible environment.

Even with the above assumptions, the Davis Canyon site meets the travel time requirements specified by 10 CFR Part 60.

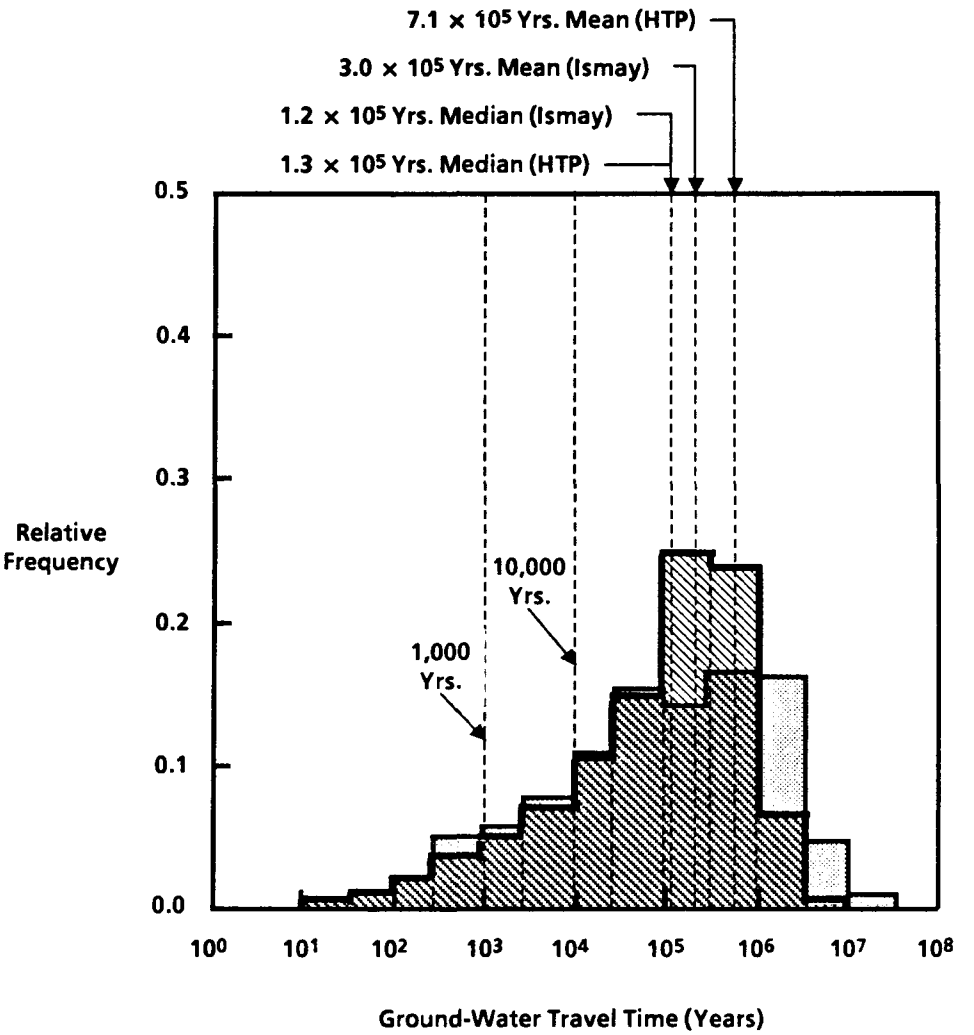
Various tectonic, climatic, and geomorphic processes that could modify the present ground-water flow regime are difficult to predict. To evaluate the effects of these processes on the existing ground-water flow regime the system was perturbed. Although the response of the system to perturbations would likely be transient (i.e., some period of time would be required to propagate the perturbation through the geologic media), only steady-state responses are analyzed and reported herein. Further details of these analyses are contained in Andrews et al. (1984).

A perturbation that could affect regional geohydrology is renewed movement along faults that cut through the Paradox Formation. Such reactivation could increase the vertical permeability along the discontinuities. The effect of this perturbation was analyzed by increasing the vertical permeability by a factor of 10 at the Verdure Graben-Abajo Laccolith intersection, at Shay Graben, and at Lockhart Basin. These modifications produced essentially no

Table 6-36. Particle Exit Layer Distribution for 1,000 Realizations of Davis Canyon Local Ground-Water System, 1-kilometer Accessible Environment (Unlikely fracture-dominated flow)

	Ismay Pressure	Honaker Trail Pressure
Elephant Canyon		
Honaker Trail (upper)		
Honaker Trail sandstone		
Honaker Trail (lower)		0.131
Ismay		0.123
Paradox Salt Cycle 5		
Paradox Salt Cycle 5 interbed		0.746
Paradox Salt Cycle 6		
Paradox Salt Cycle 6 interbed	0.501	
Paradox Salt Cycle 7	0.003	
Paradox Salt Cycle 7 interbed	0.119	
Paradox Salt Cycle 8	0.002	
Paradox Salt Cycle 8 interbed	0.165	
Paradox Salt Cycle 9	0.001	
Paradox Salt Cycle 9 interbed	0.099	
Paradox Salt Cycle 10	0.001	
Paradox Salt Cycle 10 interbed	0.053	
Paradox Salt Cycles 13-26	0.005	
Pinkerton Trail	0.033	
Molas	0.013	
Leadville Limestone	0.005	
	1.000	1.000

Note: Representatives of ground-water system by selecting combination of geohydrologic parameters.



Explanation

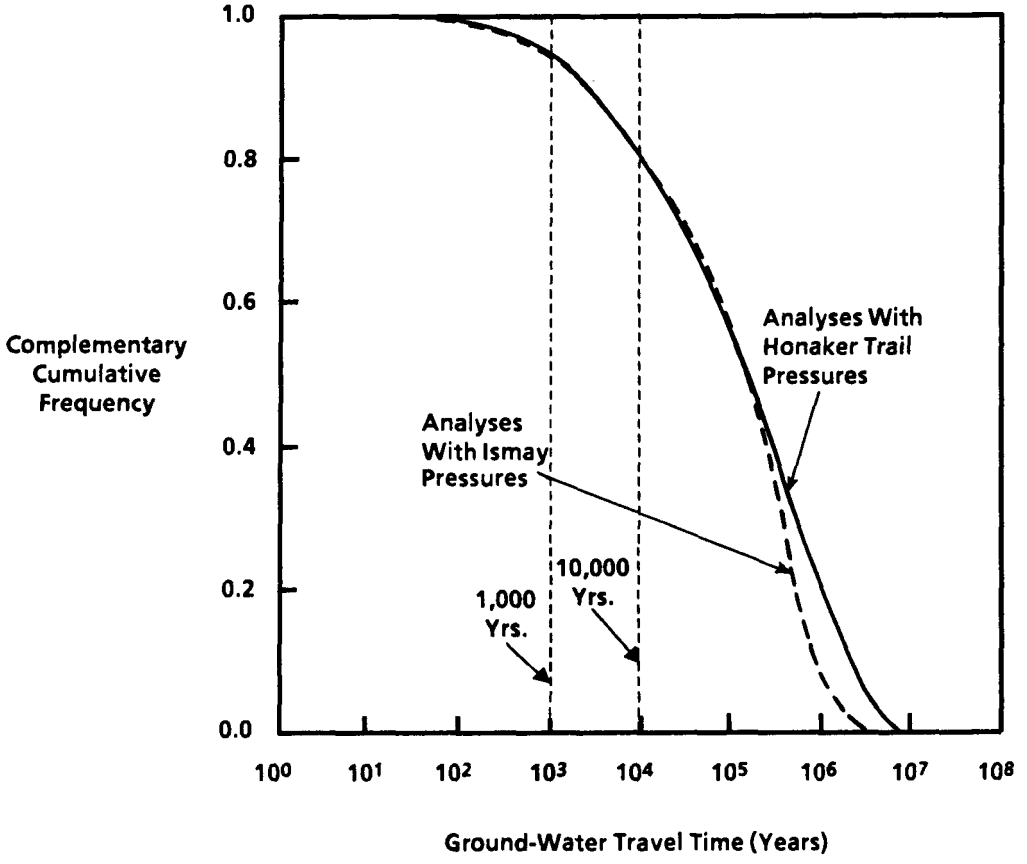
Analysis With Honaker Trail Pressure
Mean (yrs.) = 7.1 × 10⁵
Median (yrs.) = 1.3 × 10⁵

Analysis With Ismay Pressure
Mean (yrs.) = 3.0 × 10⁵
Median (yrs.) = 1.2 × 10⁵

Note: Pre-waste emplacement ground-water travel times from disturbed zone to 1 km accessible environment, based on 1,000 combinations of geohydrologic parameters.

Relative Frequency of Ground-Water Travel Times for Unlikely Conditions of Porous and Fractured Media Flow Davis Canyon

Figure 6-22



Analysis With Ismay Pressure		Analysis With Honaker Trail Pressure	
95th Percentile	5.3×10^2	95th Percentile	5.8×10^2
50th Percentile	1.2×10^5	50th Percentile	1.3×10^5
5th Percentile	1.2×10^6	5th Percentile	3.2×10^6

Note: Pre-waste emplacement ground-water travel times from disturbed zone to 1 km accessible environment, based on 1,000 combinations of geohydrologic parameters.

Complementary Cumulative Frequency for Ground-Water Travel Times for Unlikely Conditions of Porous and Fractured Media Flow Davis Canyon

Figure 6-23

Table 6-37. Summary of Pre-Waste-Emplacement Ground-Water Travel Time of 1,000 Realizations[a] of Davis Canyon Local Ground-Water System, Accessible Environment (Including fracture-controlled pathways)[b]

	Probability		Travel Time (years)
	1,000 Years	10,000 Years	Median
Ismay Pressures	0.074	0.214	1.2×10^5
Honaker Trail Pressures	0.075	0.214	1.3×10^5

(a) Representatives of ground-water system by selecting combinations of geohydrologic parameters.

(b) Assumes open and continuous fractures.

Table 6-38. Pre-Waste-Emplacement Ground-Water Travel Times to Address Variable Distance to Controlled Area Boundary[a] For Davis Canyon Using Ismay Pressures

	Distance from Disturbed Zone to Accessible Environment or Controlled Area Boundary				
	1 km	2 km	3 km	4 km	5 km
	(Likely) Porous Flow				
Median (yrs)	2.4×10^5	4.3×10^5	5.8×10^5	7.5×10^5	8.8×10^5
Probability (1,000 yrs GWTT)	<0.003	<0.001	<0.001	<0.001	<0.001
Probability (10,000 yrs GWTT)	0.045	0.20	0.012	0.009	0.006
	(Unlikely) Porous and Fracture Flow[b]				
Median (yrs)	1.2×10^5	2.3×10^5	3.2×10^5	3.6×10^5	4.0×10^5
Probability 1,000 yrs GWTT	0.074	0.046	0.036	0.030	0.026
Probability 10,000 yrs GWTT	0.214	0.171	0.142	0.128	0.118

(a) EPA 40 CFR Part 191 limits a maximum of 100 sq km controlled area. Repository location after site characterization will identify distance to controlled area boundary (which will be considered as an accessible environment). These sensitivity analyses are primarily to provide understanding on probabilities of ground-water travel times with variable distances to the controlled area boundary.

(b) Continuous open fractures have not yet been identified as possible pathways. These analyses were done to provide understanding of ground-water travel time estimates if such pathways are identified during site characterization.

change in the horizontal velocity within the Honaker Trail or vertical velocity through the Paradox Salt, and produced less than a 10 percent change in the horizontal velocity in the Leadville limestone (Andrews et al., 1984, Table 3-3).

Another set of perturbations modeled is the erosion of surface elevations of alluvial systems in the region over the next 10,000 to 1 million years. Lowering the surface elevation along the Colorado River by 30 meters (100 feet) caused a 14 percent increase in the downward flow through the Paradox Salt (Andrews et al., 1984, Section 3.4.2). This is a result of the modeled hydraulic communication between the river and the Leadville Formation along Dark and Gypsum Canyons (Andrews et al., 1984, Section 3.4.2). As the heads in the river are lowered, the heads in the Leadville Limestone are decreased, which increases the downward hydraulic gradient and velocity. Lowering the surface elevations along Indian Creek and its tributaries decreased the downward flow through the Paradox Formation by 27 percent (Andrews et al., 1984, Section 3.4.2). This is a result of the reduced heads in the Elephant Canyon and Honaker Trail and the subsequent decreased downward hydraulic gradient.

Combining the effects of increased vertical permeability through the Verdure-Graben-Abajo Laccolith discontinuity and the Lockhart Basin faults, with increased boundary heads in the Leadville Limestone and lowered surface elevations along Indian Creek, generated a 50 percent reduction in the vertical velocity through the Paradox Salt. With these changes, there is still a vertical head differential of about 131 meters (430 feet) [1,540 to 1,409 meters (5,053 to 4,623 feet)] between the Honaker Trail and Leadville. This contrasts with an approximate 188 meters (617 feet) difference (1,568 to 1,380 meters [5,144 to 4,528 feet]) for the base case simulation (Andrews et al., 1984, Table 3-3, Run 5). It is clear that greater perturbations than those theorized would be required to cause a reversal in the vertical regional hydraulic gradient direction.

Although the net impact of "purely" climatic changes on recharge to the surficial aquifers is unclear because of the competing effects of precipitation and evapotranspiration, it is conceivable that infiltration could be reduced from the present conditions. This condition was not explicitly evaluated; however, the potential effects of such a perturbation would be similar to those produced by lowering the surface elevations (and hence heads) along the principal drainage systems in the vicinity of Davis Canyon. The vertical velocity through the salt at steady state would be decreased, but it is unlikely that the heads in the Cedar Mesa, Elephant Canyon, and Honaker Trail would be lowered by a sufficient amount (about 131 meters [430 feet]) to reverse the regional gradient.

The previous analyses were conducted assuming that steady-state conditions are reestablished immediately following the perturbation. This is a conservative assumption. Some amount of time is required for the flow regime to regain steady state in the site vicinity following a change in conditions at the recharge or discharge area. Given the low permeability of the salt strata, the response will not be instantaneous. Even assuming the perturbation is felt instantaneously at the site (which is the steady-state assumption), the velocities do not change significantly.

Conclusion. Based on the conceivable processes of ground-water or brine transport, it appears that fluids will remain in the host rock for a period in excess of 10,000 years. Based on the conservative assumptions that (1) salt is a porous medium, (2) the disturbed zone extends to the brittle beds (i.e., the travel times through salt are not added), and (3) considering extremes of the range of each relevant hydrogeologic parameter, pre-waste-emplacement ground-water travel-time estimates from the disturbed zone to the accessible environment meet the requirements of 10 CFR Part 60 by a substantial margin.

6.4.2.4 Preliminary System Performance Assessment

The isolation system consists of the waste package (Section 6.4.2.2.1), engineered barrier (repository) (Section 6.4.2.2.2), and geologic (Section 6.4.2.2.3) components (subsystems) acting in concert as a system. The performance of individual subsystems is described in Section 6.4.2.3. The performance of the isolation system is described in this section from the system viewpoint.

6.4.2.4.1 Reference Case. Under reference (expected) conditions, waste packages in salt repositories will not fail for a very long time and radioactivity will not be released from the repository. The calculations in Section 6.4.2.3.3 suggest that waste packages for the Davis Canyon site will last indefinitely. The only mechanism expected to act on the package is uniform corrosion from brine which migrates to the waste package from inclusions throughout the salt. This migration is due to thermal diffusion enhanced by temperature-dependent solubility. The total volume of brine that can reach the package is limited because brine migration ceases when thermal gradients from emplaced waste no longer exist. This volume is not sufficient to corrode through the overpack. Thus, with no release from the package for an indefinite period to provide a source term to the repository and geologic subsystems, all 10 CFR Part 60 and 40 CFR Part 191 requirements would be automatically met. No release to the accessible environment is expected for at least 100,000 years because of the small expected transport distances in salt after package failure. No radioactivity is expected to be added to the Elephant Canyon aquifer until beyond 100,000 years because it is above the repository, and flow paths are directed downward.

The sensitivity of the system to early failure of packages can be tested by assuming early failure. The potential source terms for CHLW and SFPWR for the geologic subsystem are shown in Tables 6-32 and 6-33, respectively, as multiples of the EPA limits for individual nuclides. These results were determined assuming no waste form resistance and that nuclides dissolved in the available brine according to solubility limits given in Table 6-32. These tables show that, even in the case of a hypothetical package failure as early as 300 years, the EPA site limits (40 CFR Part 191) are met at the package boundary for all nuclides individually and totalled except cesium-137. There is no requirement that the EPA site limits be met at the package boundary. Travel times are such that both cesium-137 and carbon-14 will decay sufficiently to meet the EPA standards prior to reaching the accessible environment. The following sections describe results with variation in subsystem performance. These results demonstrate the impact of uncertainties in subsystem performance.

6.4.2.4.2 Performance Limits Case. This case is used to illustrate the capability of the geologic setting to restrict releases to the accessible environment in the event the waste package or engineered-barrier subsystems just barely meet regulatory requirements. A waste package lifetime of 300 years and engineered-barrier release of 10^{-5} per year of 1,000-year inventory (i.e., just meeting 10 CFR Part 60 requirements) are assumed.

For the undisturbed performance of a salt site, there are only two plausible mechanisms for radionuclide transport away from a failed waste package: (1) diffusion of radionuclides, and (2) radionuclides dissolved in brine which migrates away from the waste package. The first mechanism is driven by the concentration gradients of the radionuclides in the solid salt, while the second mechanism is driven by the concentration of brine in the solid salt.

The initial transport of brine is toward the waste package because of thermal gradient brine inclusion migration. However, after the temperatures have decayed to near ambient levels, any brine transport will be away from the waste package. The model used in this report considers brine transport away from the package to be due to a diffusion-like mechanism, i.e., the second mechanism described above. Diffusion with an enhanced empirically determined coefficient is used to describe this transport. The time periods during which the brine accumulates and then migrates away from the package are relatively short compared to the time periods of interest. Consequently, the entire release from the package is assumed to occur at package failure. The amount of the release may be limited by the release fraction from the waste form and the solubility of the radionuclide in the brine, since the amount of brine that accumulates is also relatively small. When the brine concentration decreases with distance from the waste package, the brine concentration gradient can drive brine containing radioactivity into the surrounding salt. To describe the mobility of particles, atoms, molecules, etc., by random molecular motion, Fick's classic equation (Crank, 1975, p. 2) for diffusion has been used. Implicitly, these calculations ignore advective transport due to a hydraulic gradient. As discussed in Section 6.4.2.3.5, the host rock has a very low, if not zero, hydraulic conductivity, and the assumption of a Darcian flow model also gives short travel distances.

Calculations for pure diffusion can use diffusion coefficients calculated from a theoretical basis. However, in other applications, Robertson (1974) showed that the diffusion theory can successfully model "dispersion" of radioactivity in ground-water systems with empirical diffusion coefficients. Thus, in this analysis, we use the diffusion theory to empirically determine brine "diffusion" coefficients based on the water content of field samples of salt that were obtained at various distances from a water bearing sediment inclusion in salt. These coefficients should apply for transporting dissolved radionuclides, since the resultant brine "diffusion" coefficient is about 4 orders of magnitude larger than solid-state diffusion coefficients which would apply if the radionuclide elements were to separate from brine and diffuse through salt by themselves. Additional discussion of this factor is given in succeeding paragraphs. Consequently, the diffusion analyses used these empirical brine "diffusion" coefficients to estimate the movement of radionuclides in a nuclear waste repository in salt. The analyses assumed an infinite plane source as shown in Figure 6-24 to represent the nuclear waste repository.

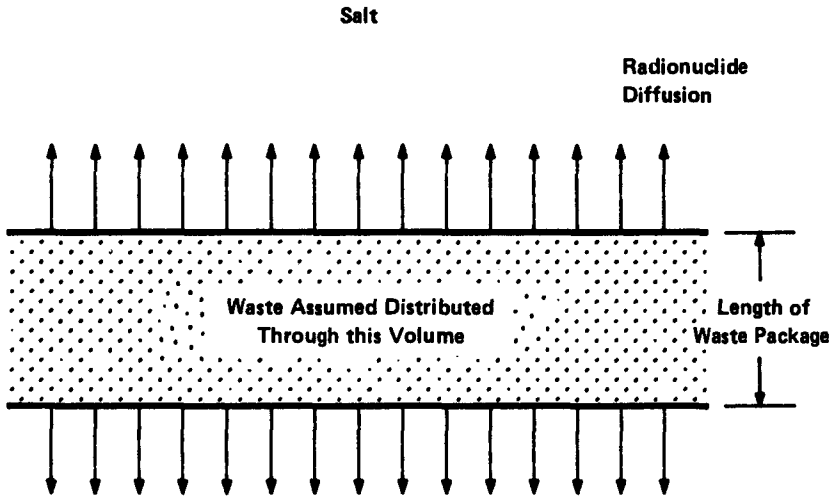
Analytical Approach. McNulty et al. (1985) give the equations that govern the transport of brine away from the waste package under a diffusion-like mechanism. This diffusion analysis for radionuclide transport ignores the relatively short times required for brine accumulation around the waste package. The analysis assumes that the thermally driven brine transport has already occurred and that the waste package releases radionuclides immediately after its failure.

To maximize the calculated curie release, the analysis assumes that all mass transfer occurs vertically as shown in Figure 6-24. In addition, the analysis does not account for the chain decay of uranium-234 and assumes all uranium-234 immediately becomes radium-226. Integration of the diffusion fluxes over intervals of 10,000 years at several distances from the release point allows direct comparison with 40 CFR Part 191 (EPA, 1985b) as if the distances chosen were different selected boundaries of the accessible environment.

Data Base and Uncertainty. The data used in the analyses consist of an empirical diffusion coefficient, radionuclide inventories and solubilities (Jansen, 1985), and total expected brine volumes (McCauley and Raines, 1985). Knauth (1982) gives data for the distribution of water in salt surrounding a brine pocket associated with a sediment inclusion in a salt mine in Weeks Island dome. Knauth (1982) used the vacuum volatilization technique of Knauth and Kumar (1981) to measure the water content of salt specimens sampled at various distances from the brine pocket. These data give an empirical brine diffusion coefficient of 4.9×10^{-12} square meter per second (1.5×10^{-4} square meter per year) when a diffusion-like process is assumed and the time of entrapment of the sediment is assumed to have occurred 75 million years ago.

In contrast, Jost (1960, p. 184) shows that transport by ordinary solid-state diffusion of sodium ions in salt occurs very slowly. Jost's correlation gives a diffusion coefficient of about 3×10^{-16} square meter per second (9.5×10^{-9} square meter per year) for a temperature of 300 C (572 F) which is higher than the maximum expected repository temperature (Section 6.4.2.1.1). The empirical brine diffusion coefficient is four orders of magnitude larger than the one given by Jost. Consequently, the diffusion analyses use the brine diffusion coefficient which gives penetration distances about two orders of magnitude greater than calculated penetration distances based on solid state diffusion of sodium ions in salt.

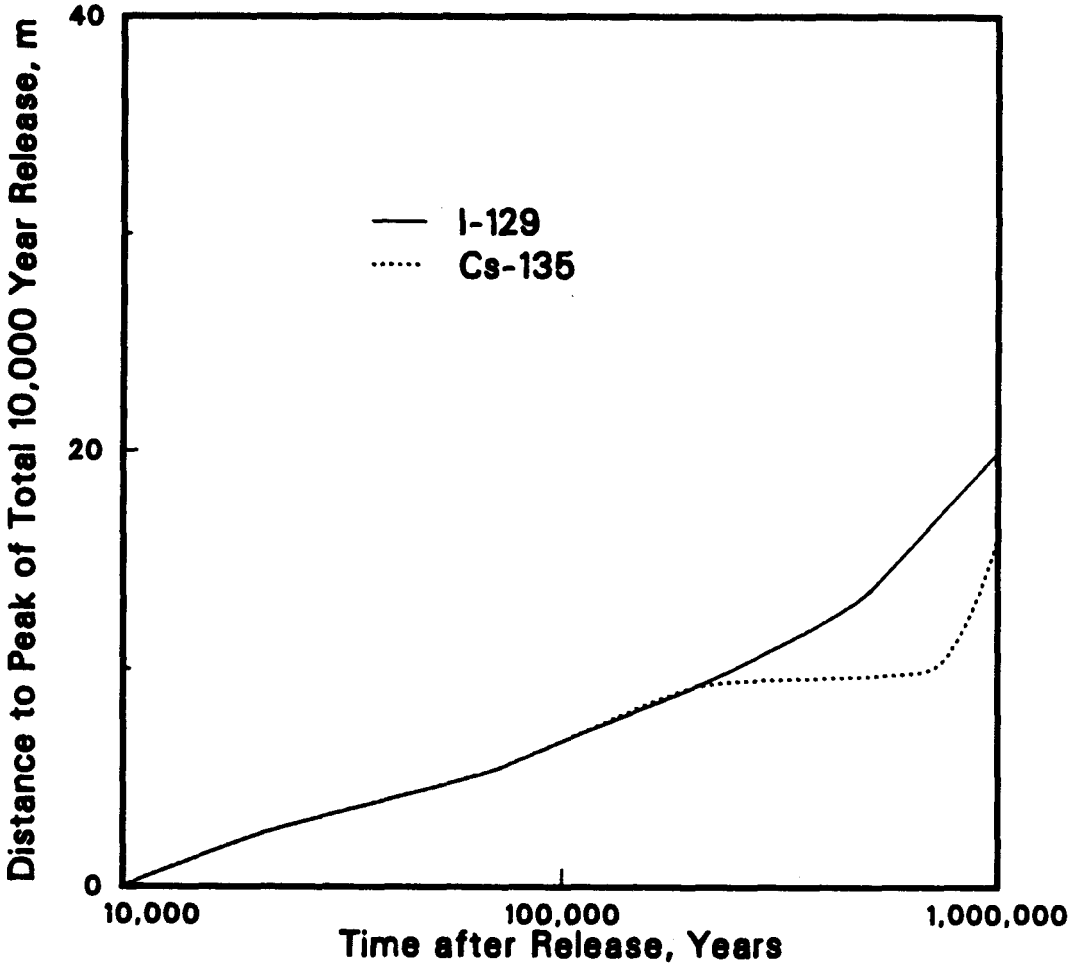
Diffusion Analyses and Results. McNulty et al. (1985) made separate diffusion calculations using brine volumes and curie inventories specific to CHLW and SFPWR waste and assuming 300-year package life and 10^{-5} per year waste form release rate. The analyses show that the total 10,000 year curie release would exceed the EPA quantities standard for a maximum penetration distance of less than 1 meter (3.3 feet). In addition, Figure 6-25 shows that after 100,000 years, the most soluble radionuclides (iodine-129 and cesium-135) have traveled less than 10 meters (32.8 feet). These transport distances are negligibly small. The disturbed zone is relatively small, approximately 15 meters (49 feet), as described in Section 6.4.2.3.5. As shown by Figure 6-25 the maximum penetration front for radionuclide transport of any element from any waste type during 100,000 years is less than 10 additional meters (32.8 feet). Thus, if a 25-meter (82-foot) thickness of host rock, including the 15-meter



Schematic of Repository as
Infinite Plane Source

Source: McNulty et al., 1985.

Figure 6-24



Travel Distances with Time at Davis Canyon for Most Soluble Radionuclides, Iodine – 129 and Cesium – 135

Source: McNulty et al., 1985.

Figure 6-25

(49-foot) disturbed zone, is available all around the repository, it is likely that radioactivity will not escape the host rock for more than 100,000 years even assuming package failure. The transport at the location (less than 1 meter [3.3 feet]) where the EPA standard is satisfied is principally iodine-129, cesium-135, and cesium-137.

6.4.2.4.3 Sensitivity of Performance to Variations in Release from the Engineered-Barrier System. Clearly, reduction in the fractional release from 10^{-5} per year to 10^{-6} per year with a 300-year package would proportionately reduce the very small transport quantities of iodine-129, cesium-135, and cesium-137 described in the previous section. The small quantities (approximately a total of 0.002 of the EPA limit) of other nuclides are not reduced because the solubility limit continues to be the factor controlling their release.

Increasing the fractional release rate to 10^{-4} of the 1,000 year inventory per year would cause the release from the engineered subsystem to the geologic subsystem of all of the iodine-129 and cesium-135 in about 10,000 years because the solubility limits of these nuclides are very large and decay is not a factor for iodine-129 and cesium-135 in the 10,000 years. This, in turn, will cause the location at which the EPA standard is satisfied to move outward from that reported in Section 6.4.2.4-2. However, the EPA standard is still met with less than 1 meter of host rock. Figure 6-25 is reasonably valid for this consideration.

6.4.2.5 Comparison with Regulatory Criteria

Table 6-39 compares the calculated results described in the immediately preceding sections, for the cases considered, with regulatory requirements, and gives results for 100,000 years (10 CFR Part 960). The expected package lifetime far exceeds the 1,000-year time frame specified by the ground-water contamination and individual protection requirements of 40 CFR Part 191. No contamination of ground water or dose to individuals is anticipated regarding these requirements as noted in the table. These calculations indicate that the expected condition is that all standards will be met. This is obvious except for the ground-water travel time requirement because of the long expected waste package lifetime.

The performance limits case demonstrates that the site is fully capable of meeting the requirements on release to the accessible environment (40 CFR Part 191) with engineered subsystem performance just meeting regulatory requirements. The cesium-137 release requirement could be met with a package lifetime of 830 years (with no waste form resistance). Alternately, if a 10^{-4} release (ONWI, 1983, ONWI-462, p. 11) is specified, a package lifetime of 430 years will provide all requirements as discussed in Section 6.4.2.3.4.

6.4.2.6 Effects of Potentially Disruptive Events and Processes

Section 6.3 considers maximum (conservative) rates for geologic and hydrologic processes to evaluate the suitability of the site with respect to the guidelines. Earlier parts of Section 6.4.2 model the performance of repository systems also assuming maximum (conservative) rates. Additional, unexpected events that could disrupt the repository would be due to either geologic processes or human interference.

6.4.2.6.1 Geologic Processes. The energy driving geologic systems comes from the earth (tectonics) and the atmosphere (climate). The effect of large, unanticipated changes in the climate and increases in the rate of tectonism are discussed below.

Climate. The plausible extremes of climate during the Quaternary were experienced in the Paradox Basin. These were alternating pluvial episodes (periods of high rainfall and cool temperatures) accompanying glaciation to the north, and intervals characterized by hot and dry conditions accompanying the interglacial conditions. These conditions are expected to recur several times during the next one million years. As described in Section 3.2.2.3, the expected effect of these extremes on geomorphic processes would be to decrease erosion. There are insufficient data to evaluate the influence of climatic change on salt dissolution. The presently available data indicate that there is no dissolution within the site. The closest known or potential dissolution feature to the geologic repository operations area is 14 kilometers (9 miles) away. Assuming an active dissolution front at this distance, and assuming

Table 6-39. Comparison of Performance Assessment Results With Postclosure Regulatory Requirements

Regulatory Requirement	Expected Performance Level for Reference Case (Expected Condition)	Performance Limits Case: 300-Yr Pkg. 10^{-5} Release	Sensitivity Analyses: 300-Yr Pkg. 10^{-6} Release	Sensitivity Analyses: 300-Yr Pkg. 10^{-4} Release
Contamination of Major Ground-Water Source (40 CFR Part 191)	0	0	0	0
Dose for Individual for First 1,000 years after closure[a]	0	0	0	0
Ground-Water Travel Time (10 CFR Part 60)	(b)	(b)	(b)	(b)
Package Lifetime 300 to 1,000 years (10 CFR Part 60)	10,000 yr	Specified 300 yr	Specified 300 yr	Specified 300
Engineered Subsystem Release (10 CFR Part 60)	0 Release	Specified to meet	Specified to meet	All but Cs-137[c]
Release to Accessible Environment (40 CFR Part 191)	0 Release	Meets release requirements less than 1 meter beyond disturbed zone		

(a) Individual protection requirement given in 40 CFR Part 191.

(b) Maximum 10,000-year travel distance = 50 m; therefore, requirement is met if accessible environment is selected greater than 50 m plus disturbed zone allowance (15 m), or a total of about 70 m from repository.

(c) The 10^{-4} fractional release does not automatically cause violation of the 10^{-5} 10 CFR Part 60 requirement because of solubility limitations. All nuclides, except cesium-137 with solubility limits and 10^{-4} package release, meet the 10^{-5} requirement.

that the structural, stratigraphic, and hydrogeologic configuration is such that the dissolution front would migrate directly toward the geologic repository operations area, that dissolution front would have to migrate at a rate of 1.45 meters (4.75 feet) per year to reach the repository in 10,000 years. This rate can be compared to measured rates of salt dissolution front advance in other areas which are 0.034 to 0.082 meter (0.11 to 0.27 foot) per year in the Texas Panhandle (Gustavson et al., 1980, pp. 24-25) and less than 0.02 meter (0.05 foot) per year at the WIPP site in New Mexico (Weart, 1981, p. 429). If active dissolution fronts exist in the candidate area, and were advancing at even 5 percent of this rate, abundant geomorphic and hydrologic indicators (such as numerous strongly saline springs) would exist. No such indications have been observed within the candidate area. Climatic changes could directly affect ground water by increasing or reducing recharge. Based on assumed changes that exceed plausible extremes, the effect on seepage rates (Section 6.4.2.5) is found to be insignificant compared to uncertainties in rock permeabilities.

Tectonics. There is no reasonable basis for expecting that a repository would be disrupted by the development of new faults or other structures in the Paradox Basin. It is not known whether regional uplift is continuing. Uplift rates characteristic of orogenesis are neither observed nor expected, because the site is distant from any modern lithospheric plate margin. The highest known long-term rate of epeirogenic uplift is 5.2×10^{-4} meter per year (1.7×10^{-3} foot per year), associated with the Colorado Plateau (Stone and Webster Engineering Corporation, 1978). This greatly exceeds what plausibly can be expected in the Paradox Basin. However, even if it is assumed that these conditions could arise and continue in the region during the next one million years, and that river incision could keep pace with uplift, the repository would not be exhumed.

Differential uplift of the recharge zone of the deep basin aquifer would increase the regional hydraulic gradients. The effects of such perturbations on hydraulic gradients are insignificant compared to uncertainties in salt permeabilities.

As discussed in Section 3.2.5.2, possibly the most significant source of seismicity to the Davis Canyon site outside the Paradox Basin is near Capitol Reef, approximately 100 kilometers (62 miles) southwest of the site in south-central Utah. Although seismicity has only been monitored there since 1978, it represents the most macroseismically active area observed to date within the Colorado Plateau interior, with the exception of the Book Cliffs-eastern Wasatch Plateau mining-induced seismicity. Although the largest earthquake was only a M_L 3.6, the seismicity in the Capitol Reef-Henry Mountains region (including the epicentral area of a M_L 3.5 earthquake that occurred southeast of Hanksville on May 3, 1983) probably represents an occurrence of Basin and Range extensional tectonism. Because M_L 6 to 7 earthquakes have occurred to the west in the extensional Intermountain seismic belt, the seismicity in the Capitol Reef-Henry Mountains region may represent a source of earthquakes that may impact the Davis Canyon site.

6.4.2.6.2 Human Interference.

Regulatory Requirements. Human activities give rise to another group of possible disruptions. These disruptions are addressed, in a general manner, by the System Guideline of 10 CFR 960.4-1. This guideline states that the geologic repository shall consist of a system of multiple natural and engineered barriers. These barriers will physically separate the radioactive waste from the accessible environment after closure in accordance with the requirements set forth in 10 CFR Part 60 and 40 CFR Part 191.

Human interference is then addressed directly by 10 CFR 960.4-2-8:

> The site shall be located such that activities by future generations at or near the site will not be likely to affect waste containment and isolation. In assessing the likelihood of such activities, the DOE will consider the estimated effectiveness of permanent markers and records required by 10 CFR Part 60...

Implementation of Regulations. To date, the NRC Regulation (10 CFR Part 60) referred to in the System Guideline has received relatively little attention in the performance assessment literature. Such analyses need to be site-specific and sites are not yet chosen. However, the cumulative release requirements of the EPA standard for the complete disposal system (40 CFR 191.13) have received greater attention, even to the extent that a methodology has evolved which is specially adapted for showing compliance with the EPA standard.

To implement this methodology with respect to human interference, those human activities are specified which could potentially compromise the performance of a repository. Then, utilizing a rather rigorous procedure, these activities are coupled conceptually with other features, processes, and events, which may be highly site-specific, to form scenarios. The brine-pocket-hit scenario is an example. Here, the human activity of drilling through the repository is coupled with a system feature--a brine pocket with near lithostatic pressure lying directly beneath the repository. The study by Arthur D. Little, Inc. (1980) provides a very thorough discussion of many features, processes, and events. Bingham and Barr (1979) use event trees to show how such phenomena are coupled conceptually by the use of event trees. Cranwell et al. (1982, SAND81-2573; 1982, SAND80-1429) then apply the complete methodology. The latter authors employ statistical techniques to account for parameter uncertainties and scenario probabilities in a procedure which permits direct comparison with the EPA standard.

A variant of the above methodology probably will be adopted for the site characterization program, where data will be sufficient to support site-specific analysis. Here, however, to support a nomination for site characterization, the objective is somewhat more limited, and such a site-specific analysis, although desirable, is not yet credible because of the lack of site-specific data. The objective in this report is to show, in accordance with 10 CFR Part 960, Appendix III, that the available evidence does not support a finding that the site is not likely to qualify under 10 CFR 960.4-2-8-1(a). Site-specific data and analyses will be required for formal site nomination. Furthermore, issues to be identified below will be dealt with during the site characterization program. However, the literature for generic sites and certain specific locations different from the site which is the subject of this report is sufficiently extensive at this time to permit a plausible argument in favor of nomination for site characterization.

Release Scenarios. Many different features, processes, and events can conceivably affect the operation of a nuclear waste repository, as illustrated by the comprehensive lists of Burkholder (1980) and Koplik et al. (1982). Scenarios formed from phenomena have been developed and examined for more than a decade. Although most such studies focus on bedded salt, many of the conclusions are transferrable to a domed-salt lithology. The works of Claiborne and Gera (1974, ORNL/TM-4639), and others, indicate that some of the phenomena will be sufficiently improbable that they will not significantly contribute to risk. Burkholder (1983, ONWI-286), in fact, notes "an emerging consensus that scenarios involving meteorite impacts, sabotage, nuclear warfare, erosion, criticality, volcanism, diapirism, stored energy release, and natural salt dissolution are unimportant...to the performance of nuclear waste isolation systems." Certainly no scenarios will be excluded a priori from a site-specific analysis. However, the literature strongly suggests that such scenarios will be insignificant contributors to risk.

At the same time, however, there remain inconsistencies in the literature regarding certain human intrusion scenarios which will require additional analysis. These inconsistencies relate, to a lesser extent, to ground-water transport scenarios, and to a greater extent, to direct-access scenarios. Pepping et al. (1983, NUREG/CR-2402) analyzed several U-tube type ground-water transport scenarios and found a strong dependence on source characterization. For those cases in which the entire repository, or even one entire room, was exposed to the invading fluid, which assumed leach limitation, the radionuclide release limits of the EPA standard (Draft 19) were slightly exceeded. However, when a mixing-cell model was used with a solubility-limited source, releases were negligible with respect to the standard. The fact that the EPA standard was exceeded in some cases is not considered to be significant, since the aquifer transmissivities of this generic bedded-salt site were unrealistically high. Further, the study was designed to illustrate risk methodology rather than to evaluate a real site against the EPA standard. The results are significant, however, in two respects, both of

which are noted by the authors. First, the need for realistic modeling of the engineered barrier and the waste package is indicated, so that the source term may be determined more precisely. Second, a need for more precise modeling of the borehole is also indicated. This analysis assumes that the boreholes stay open in excess of 10,000 years, whereas, salt creep quite possibly will close the boreholes to fluid flow within a relatively short period of time.

Pepping et al. (1983, NUREG/CR-2402) also analyzed two direct access scenarios, namely a direct-canister-hit scenario and a brine-pocket-hit scenario. For the former, it was arbitrarily assumed that one-fourth of the canister contents were removed each time a canister was penetrated. For the latter, another, rather arbitrary source-term assumption was adopted; 0.025 of the contents of one room was released over a time period of 100,000 years. For both scenarios the location of the borehole was treated probabilistically. The authors noted that "The penetration scenarios (direct-canister-hit and brine-pocket-hit) indicate potentially serious consequences." However, the possibility of a sudden and catastrophic failure of waste packages has since been considered. Harper and Raines (1985, p. 499) considered a direct hit scenario and analyzed, stochastically, the release of radionuclides to the environment. This study showed that there was a high expectation that EPA requirements would be met with a repository in salt. INTERA (1985, BMI/ONWI-553) analyzed the intrusion of a borehole into the repository and calculated the subsequent dissolutioning and radionuclide releases to the accessible environment. INTERA (1985, BMI/ONWI-553) overestimated borehole flow rates, ignored any containment by the waste package, and ignored the likely plugging of the borehole by silt or other materials to add conservatism to the calculations. Still, releases were below draft EPA (1982a) standards when the accessible environment was assumed to start at 10 kilometers (6.2 miles).

INTERA (1985, BMI/ONWI-553) found that the maximum potential dissolution from a borehole is limited. Creep closure ultimately closes the borehole. Therefore, they concluded that salt dissolutioning in existing boreholes, for the case considered, would not provide a pathway for radionuclide release.

In the Waste Isolation Plant Project (WIPP) Safety Analysis Report (DOE, 1983), six different scenarios were analyzed. It is interesting to note that in all of these scenarios, including the three analyzed by Pepping et al. (1983, NUREG/CR-2402), the consequences were found to be insignificant. The whole body dose commitment was less, in all cases, than the recommended dose limit of 500 mrem per year. Consequences were not compared with the EPA standard in this study. The major difference between the two analyses is threefold. First, in the U-tube scenarios, "the dissolution of radioactive waste is assumed to be controlled only by salt dissolution in the waste storage area with no credit taken for the waste containers" (DOE, 1983). Second, for the direct access scenarios, the presence of a mud pit is characterized for the drilling operation, along with drying, resuspension, and atmospheric transport of radionuclides. Third, for the brine-pocket hit, it is also assumed that the flow of brine is shut off after 24 hours of release. It is not proposed here that the mud pit and atmospheric transport be considered in further scenario refinement, since the status of such an assumption with respect to the EPA standard is questionable. However, further characterization of the source term for ground-water transport, brine-pocket-hit, and direct hit scenarios are desirable and will be considered during site characterization.

INTERA (1985) analyzed a U-tube connection between a single borehole (inadvertently drilled or abandoned before construction of repository), a repository storage room, and an access shaft that still offered a potential hydraulic connection despite being backfilled and plugged. The analyses maximize the predicted releases by assuming the hydraulic connection remained open for 10,000 years. Pressure boundary conditions were provided from a regional hydrologic analysis. The flow was calculated in a local flow model taking into account density variations due to increased salinity of the water in the salt units and the increased temperature due to the generation of heat by the radioactive waste. INTERA (1985) showed that predicted releases from a U-tube connection were several orders of magnitude lower than draft EPA (1982c) standards when the accessible environment starts at 10 kilometers (6.2 miles). Future site-specific analyses for site characterization will calculate releases at distances much closer to the point of radionuclide release.

Harwell et al. (1982, Vol. I and II) examined a salt-solution mining scenario, the cavern for which intercepted the repository. The host formation was considered to be the Hainesville Dome of the East Texas Salt Dome Basin. The probability of such a scenario, of course, would be higher for a dome than for a bedded-salt site (Burkholder, 1980). It was assumed that the mine produced one million tons of salt per year and operated for up to 50 years without detecting radioactivity. It was further assumed that three percent of the salt was ingested, with an average rate per person of 1,800 grams of salt per year. The consequences were presented in various ways; for example, a 70-year individual dose to the whole body resulting from a one-year period of ingestion. Results varied depending on the time from repository closure. They exceeded background radiation by three orders of magnitude at 100 years postclosure, and by one order of magnitude at 1,000 years postclosure (Harwell et al., 1982). A comparison with EPA standards was not performed.

The same basic scenario was examined by ONWI (1981, ONWI-320[1]). Consequences, as determined by this study, were much less severe. For a 70-year individual dose to the whole body resulting from a one-year period of ingestion, results were approximately equal to background radiation at 100 years postclosure and were about two orders of magnitude less than background at 1,000 years postclosure, i.e., the results here were less than those obtained in the study of Harwell et al. (1982) by three orders of magnitude. Again, consequences were not compared with the EPA standard. One significant difference between the two calculations is the assumed level of preferential dissolution, which, over a 50-year period, resulted in a 61 percent exposure of the wastes in the study of Harwell et al. (1982) and 2.5 percent exposure in the task-force study (ONWI, 1981, ONWI-320[1]). Another significant difference is the existence of a sump. A relatively immobile sump, composed of insoluble material, forms at the bottom of a cavity, and exposed waste packages would probably fall into this region. The study of Harwell et al. does not account for the presence of this sump; the ONWI study does.

None of the above studies consider the effectiveness of passive-control measures although they are required by the regulations. In fact, it is not clear at this point how quantitatively to account for these measures. However, it is the consensus view of an ONWI task force (Human Interference Task Force, 1984, BMI/ONWI-537) that the passive-control measures now being considered would be effective in reducing the risk of human intervention. Further, the NRC's final rule (10 CFR 60.2) does not require the analysis of human intrusion activities at the site (e.g., solution mining) if appropriate markers are used at the site so that future generations are aware of the hazards that exist. The DOE plans to use such markers and, therefore, does not plan to model solution mining.

Concluding Remarks. Previous research suggests that various scenarios will not pose a significant hazard at the site. For other scenarios, involving both ground-water transport and direct access, research is inconsistent at this point. However, for the latter group of scenarios, current research does indicate a strong sensitivity to the assumed source term. This research, especially for the case of solution mining, also appears to indicate that the consequence is reduced with increasing scenario refinement. In a general sense, this inverse relation of consequence to scenario refinement results from the fact that, in order to simplify the relatively complex phenomena at the repository and waste-package scales, authors have opted for conservatively high estimates of the source rate. The DOE will actively pursue realistic scenario quantification, both through ongoing programs in site assessment, and engineering and shaft-seal performance assessments which are planned. The available evidence does, then, not support a finding that the site is not likely to qualify under 10 CFR 960.4-2-8-1(a). Furthermore, the refined characterization of the critical scenarios, as typified above, will probably show that this site qualifies for final nomination under 10 CFR Part 960, Appendix III.

6.4.2.7 Conclusions

Preliminary performance assessments have been completed for the Davis Canyon site. These analyses are based on currently available codes, conceptual models, preliminary data (mostly generic to salt but not site-specific), and interpretations. To allow for uncertainty, assumptions are generally made that tend to minimize package lifetime and maximize radionuclide releases. There is no evidence from these preliminary performance assessments that a

repository at the site will not comply with the system criteria, nor that the engineered subsystems would not be able to perform as required.

During the course of site characterization, key data and technology areas that will be emphasized are (1) brine migration; (2) solubility and other corrosion and waste-form behavior characteristics, using site-specific brines; (3) characterization of sources of water; and (4) in situ salt properties. Increased understanding, leading to more accurate modeling techniques, as well as the obvious necessity for site-specific data are needed.

6.5 CHAPTER 6 REFERENCES

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14 CFR Part 77, Objects Affecting Navigable Airspace.

15 CFR Part 930, Regulations under the Coastal Zone Management Act of 1972 (16 USC Secs. 1451-1464).

25 CFR Part 261, Preservation of Antiquities.

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33 CFR Part 320, General Regulatory Policies.

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33 CFR Part 325, Processing of Department of the Army Permits.

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33 CFR Part 330, Nationwide Permits.

36 CFR Part 9, Regulations under the Organic Act of the National Park Service (16 USC Secs. 1901-1912).

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36 CFR 60.5, Nominations by the State Historic Preservation Programs.

36 CFR Part 62, National Natural Landmarks Program.

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36 CFR Part 65, National Historic Landmarks Program.

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36 CFR Part 800, Procedures for the Protection of Historic and Cultural Properties.

40 CFR Part 50, National Primary and Secondary Ambient Air Quality Standards.

40 CFR Part 51, Requirements for Preparation, Adoption, and Submittal of Site Implementation Plans.

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40 CFR Part 60, Standards of Performance for Fossil-Fuel Fired Steam Generators.

40 CFR Part 61, National Emission Standards for Hazardous Air Pollutants.

40 CFR 81.300-85.408, Protection of Environment, Section 107 Attainment Status Designations.

40 CFR Part 110, Discharge of Oil.

40 CFR Part 116, Designation of Hazardous Substances.

40 CFR Part 117, Determination of Reportable Quantities for Hazardous Substances.

40 CFR Part 121, State Certification of Activities Requiring a Federal License or Permit.

40 CFR Parts 122-124, 260-265, 270, Solid Waste Disposal Guidelines.

40 CFR Part 125, Criteria and Standards for the National Pollutant Discharge Elimination System.

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43 CFR Part 4700, Regulations under the Wild and Free-Roaming Horses and Burros Act (16 USC Secs. 1331-1340).

43 CFR Part 8560, Designated Wildernes Areas; Procedures for Management.

49 CFR Parts 171-177, Hazardous Materials Regulations.

49 CFR Part 178, Shipping Container Specifications.

50 CFR 10.13, Regulations under the Migratory Bird Treaty Act (16 USC Secs. 703-711).

50 CFR 17.11, 17.12, 17.94, 17.95, and 17.96, Endangered and Threatened Wildlife and Plants.

50 CFR Part 22, Eagle Permits.

50 CFR Parts 25, 27, 28, 29, Regulations under the National Wildlife Refuge System (16 USC Secs. 668dd-668ee).

50 CFR Part 35, Wilderness Preservation and Management.

50 CFR Part 222, Endangered Fish or Wildlife.

50 CFR Part 226, Designated Critical Habitat.

50 CFR Part 227, Threatened Fish and Wildlife.

50 CFR Part 402, Interagency Cooperation - Endangered Species Act of 1973.

50 CFR Parts 402, 405, 450, 451, 452, and 453, Regulations under the Endangered Species Act of 1973 (16 USC Secs. 1531-1543).

50 CFR Part 424, Listing Endangered and Threatened Species and Designating Critical Habitat.

American Antiquities Act, 16 USC Sec. 433.

American Indian Religious Freedom Act of 1978, 42 USC Sec. 1996.

Archaeological and Historic Preservation Act, 16 USC Sections 469-469c.

Archaeological Resources Protection Act of 1979, 16 USC Secs. 470aa-47011.

Bald and Golden Eagle Protection Act, 16 USC Secs. 668-668d.

Bridge Act of 1906, Bridges over Navigable Water, 33 USC Sec. 491 et seq.

Canyonlands National Park Act, 16 USC Section 271.

Clean Air Act, as amended, 42 USC Secs. 7401-7642.

Coastal Barrier Resources Act, 16 USC Secs. 3501-3510.

Coastal Zone Management Act of 1972, 16 USC Secs. 1451-1464.

Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 USC Sec. 9601 et seq.

Cooperative Plan; Hunting and Fishing Permits, 16 USC Sec. 670a and supplement.

Endangered Species Act of 1973, 16 USC Secs. 1531-1543.

Farmland Protection Policy Act, 7 USC Secs. 4201-4209.

Federal Land Policy and Management Act of 1976, 43 USC Secs. 1701-1782.

Federal Water Pollution Control Act, Clean Water Act of 1977, 33 USC Secs. 1251-1376.

Fish and Wildlife Coordination Act, 16 USC Secs. 661-666c.

Forest and Rangeland Renewable Resources Planning Act, 16 USC Secs. 1600-1676.

General Bridge Act of 1946, Construction and Operation of Bridges, 33 USC Secs. 525 et seq.

Hazardous Materials Transportation Act, 49 USC Secs. 1801-1812.

Hazardous & Solid Waste Amendments of 1984, 42 USC Secs. 6901-6987.

Historic Sites, Buildings and Antiquities Act, 16 USC Secs. 461-469c.

Interstate Commerce Act, Part II; Motor Carriers, 49 USC Section 303, Definitions.

Marine Protection, Research and Sanctuaries Act of 1972, 33 USC Secs. 1401-1444.

Materials Act of 1979, 30 USC Secs. 601-604, 611.

Migratory Bird Treaty Act, as amended, 16 USC Secs. 703-711.

Multiple-Use Sustained-Yield Act, 16 USC Secs. 528-531.

National Environmental Policy Act of 1969, 42 USC Sec. 4332.

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National Historic Preservation Act of 1966, as amended, 16 USC Secs. 470-470w-6.

National Park System Mining Regulation Act, 16 USC Secs. 1901-1912.

National Trails System, 16 USC Secs. 1241-1251.

National Wildlife Refuge System Administration Act of 1966, 16 USC Secs. 668dd-668ee.

Noise Control Act of 1972, Quiet Communities Act of 1978, 42 USC Secs. 4901-4918.

Nuclear Waste Policy Act of 1982, 42 USC Secs. 10101-10226.

Objects Affecting Navigable Air Space, 49 USC Sec. 1501.

Organic Act of the National Park Service, 16 USC Section 1.

Permits to Examine Ruins, Excavations, and Gathering of Objects; Regulations, 16 USC Section 432.

Preservation of Parklands, 23 USC Section 13.

Quiet Communities Act of 1978, 42 USC Section 13.

Rivers and Harbors Act, 33 USC Secs. 401-413.

Safe Drinking Water Act, 42 USC Secs. 300f-300j-10.

Sikes Act Amendments of 1978, see Cooperative Plan; Hunting and Fishing Permits, 16 USC Sec. 670a.

Solid Waste Disposal Act, Resource Conservation and Recovery Act of 1976, 42 USC Secs. 6901-6987.

Taylor Grazing Act, 43 USC Secs. 315-316o.

U.S. Department of Transportation Acts, see Preservation of Parklands, amd Interstate Commerce Act.

Wild and Scenic Rivers Act, 16 USC Secs. 1271-1287.

Wild Free-Roaming Horses and Burros Act as amended, 16 USC Secs. 1331-1340.

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6.5.3 State of Utah Laws

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Forestry Utah Const. Art. XVIII, Sec. 1, Utah Code Ann. Secs. 24-2-3 and 12, 65-1-108, and 65-2-1 to 4 (1953 & Supp. 1983).

Hazardous Materials, Utah Code Ann. Sec. 41-6-154.

Hazardous Waste Facilities Management Act, Utah Code Ann. Sec. 26-14b.

Hazardous Waste Facility Siting Act, Utah Code Ann. Secs. 26-14a-1 through 26-14a-9.

(Heritage Tree Protection, see Parks and Recreation, Heritage Trees)

(License for Well Drillers, see Water and Irrigation, Wells)

Materials Permit, Utah Code Ann. Sec. 65-1-15(4), (rev. 1983; proposed for amendment 1985).

Mined Land Reclamation Act, Utah Code Ann. Secs. 40-8-1 et seq. (1981 ed. & Supp. 1983).

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Parks and Recreation, Utah Code Ann. Secs. 63-11-1 to 65, 65-1-108, and 65-2-1 to 4 (1953 & Supp. 1983).

Resource Development Coordinating Committee Act, Utah Code Ann. Sec. 63-28a-1 et seq. (rev. 1985).

Rights-of-Way, Utah Code Ann. Secs. 65-2-1 through 65-2-4.

Safe Drinking Water Act of Utah, Utah Code Ann. Secs. 26-12-1 to 26-12-12 (1981 ed.).

Solid and Hazardous Waste Act, Utah Code Ann. Secs. 26-14-1 to 26-14-18 (1953, 1984 ed.).

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State Lands, Surface Leases, Utah Code Ann. Sec. 65-1-108.

Utah Air Conservation Regulations, Utah State Division of Health, Conservation Committee, (rev. January 4, 1985).

Utah Solid Waste Disposal Regulations (Utah State Board of Health) (adopted 1974, amended 1981).

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Utah Water Quality Standards, Utah State Division of Health, Wastewater Disposal Regulations, Part VII, Underground Injection Control Program, May 2, 1985.

Water and Irrigation, Relocation of Natural Streams, Utah Code Ann. Sec. 73-3-29.

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Water Pollution Control Act of Utah, Utah Code Ann. Secs. 26-11-1 to 26-11-20 and 26-15-4 (Supp. 1984).

Wildlife Resources Code of Utah, Utah Code Ann. Secs. 23-13-1 et seq., 23-15-1 et seq., 23-16-1 et seq., 23-17-1 et seq., 23-18-1 et seq., and 23-21-1 et seq. (1953).

APPENDIX 6-A

ESTIMATION OF THE EXTENT OF THE DISTURBED ZONE

This Appendix presents only a preliminary and conservative description of the "disturbed zone" and, in view of the limited thermal, mechanical, and hydrologic data existing on the host rock at the site, estimates of the disturbed zone are very likely to be revised following site characterization. The extent of the disturbed zone depends on the interaction of thermal, mechanical, and hydrologic effects. The disturbed zone is defined as "that portion of the controlled area, excluding shafts, whose physical or chemical properties are predicted to change as a result of underground facility construction or heat generated by the emplaced radioactive waste such that the resultant change of properties could have a significant effect on the performance of the geologic repository" (10 CFR 960.2, DOE General Guidelines for Recommendation of Sites for Nuclear Waste Repositories, December 6, 1984, p. 3). The definition is consistent with that given in 10 CFR Part 60; however in order to be useful, the dimensions of the disturbed zone must be quantified.

What Constitutes a Significant Effect on Performance? The guidelines specify that "significant effect" be evaluated. However, there is no definition of this phrase. The following discussion defines "significant effect." Since the disturbed zone is associated with the geologic setting performance measure, a significant effect must be defined relative to changes in ground-water flow or radionuclide retardation that jeopardize the ability of a particular site and associated repository design to satisfy the radionuclide release limit to the accessible environment. There are two ways in which changes might jeopardize the ability to demonstrate compliance with radionuclide release limit standards:

1. Changes in ground-water flow characteristics or radionuclide retardation characteristics over a sufficient portion of the path to the accessible environment that the ability to meet the limit on release to the accessible environment is jeopardized.

2. Changes cause sufficient disruption over some limited portion of the path such that uncertainties in predicting long-term behavior are large enough to warrant discounting that part of the path in demonstrating compliance with the performance measures.

If condition (1) exists, it is likely that a site will be disqualified; in practical terms, the definition of a disturbed zone within an acceptable site is best defined by condition (2) above.

Potential Causes of Changes. The processes and phenomena that might affect long-term ground-water flow and radionuclide transport have been identified as:

Construction and Operation Related

- Mechanical effects on properties of rock
  - Induced fractures
  - Changes in existing fracture aperture
  - Crystal relaxation
  - Subsidence due to room closure

- Chemical effects on radionuclide transport
  - Introduction of oxygen, exhaust gases, etc.
  - Introduction of microbiologic organisms.

Waste Related

- Thermal-Mechanical
  - Thermal expansion of rock
    - changes in permeability
    - changes in porosity
    - uplift of stratigraphy
  - Creep closure of fractures
    - resultant rock flowage
    - closure of fractures

- Thermal-Hydrologic
  - Fluid density and viscosity changes
  - Brine migration

- Thermal-Chemical
  - Changes in natural chemical reaction rates, especially dehydration

- Radiation
  - Radiolysis of ground water
  - Crystal structure changes.

The definitions of the disturbed zone presented in the DOE Guidelines and in 10 CFR Part 60 explicitly mention changes resulting from underground facility construction and heat generated by the emplaced radioactive wastes. Therefore, this discussion includes operational effects (e.g., effects of ventilation), radiation effects, heat effects, and construction effects.

Physical Extent of Potential Changes. At this time, there are neither sufficient site-specific data nor sufficient definition of the site-specific repository design to precisely quantify the extent of the disturbed zone. However, estimates of the extent of various effects can be made from observations of salt behavior in mines at other locations and general knowledge of the change of salt properties with temperature and pressure from laboratory tests and calculations.

Construction and Operation Related Changes. Summaries of existing data related to flow or mechanical effects are presented below. The present data indicate that mechanical effects may be limited to no more than 15 meters (49 feet) from the excavations (rooms, tunnels, etc.). Field and laboratory measurements show that associated crystal relaxation tends to affect hydrologic properties of the host salt (e.g., permeability) only a very few meters, typically less than 10, into the walls of the pillars. Specific evidence includes the following:

1. Field observations in Cote Blanche Island salt mine (Golder Associates, 1977, pp. 70-71) and Weeks Island Mine (Acres American, Inc., 1979, p. 20) indicate that mechanical effects of excavation and resulting relaxation of the host rock causes fracturing and slabbing of the salt to a depth no greater than 1 to 2 meters (3.2 to 6.6 feet) into the pillars for rooms that averaged about 8 meters (25 feet) in height.

2. Additional field evidence is developed from the use of extensometers to measure displacements around a 5.5-meter (18-foot) shaft in salt in Saskatchewan at a depth of 939 meters (3,080 feet) (Barron and Toews, 1963, p. 122). These measurements indicated constant-volume creep at distances into the rock up to 2.1 meters (6.9 feet) and evidence of compaction of excavation-damaged rock in a surface "skin" about 1.2 meters (4 feet) thick. Barron and Toews (1963, p. 122) state, "The fact that creep proceeds without change of volume between the 4-foot and 10-foot points indicates that during the period of observation, there is no significant change in material properties of the salt between these two depths."

3. In situ permeability tests have been conducted in Grand Saline and Weeks Island mines (Aufricht and Howard, 1961, and Acres American, Inc., 1977; 1979). In these tests, with packers set at varying depths, permeabilities decreased significantly with depth from the mined opening: at 0.6 to 1.5 meters (2 to 5 feet), permeabilities averaged about 0.3 millidarcy with measurements as high as 6 millidarcys; and at 4.5 to 9 meters (14.8 to 29.5 feet), permeabilities ranged from 1.5 down to 0.001 millidarcys. These results are consistent with the slabbing observations and suggest a disturbed zone extending no more than a few meters (typically 1 to 2 meters [3.3 to 6.6 feet]).

4. The interpretation of these observations is aided by laboratory tests showing that salt permeability depends on confining stress. Results from several sources (Reynolds and Gloyna 1960; Lai, 1971; Sutherland and Cave, 1978) show permeability reduces by 5 to 6 orders of magnitude as confining stress increases from zero to 70 mPa (about 10,000 psi). Results of such laboratory work were compiled by Isherwood (1981).

5. Nair and Singh (1974) discuss a creep-rupture failure mechanism through which macroscopic fractures might be generated at a salt shaft or tunnel opening. Such ruptures might occur in a shallow zone (1 to 2 meters [3.3 to 6.6 feet]) around an opening, but propagation of the failed zone would be prevented by increased confining pressures at greater depth into the pillars (Kelsall, et al., 1982, ONWI-405, p. 88).

6. Field measurements by the DOE (1983, Figure 9-1; 1985, Figure 4-3) show that extensometer displacements end approximately 15 meters (49 feet) above the roof of a tunnel in a bedded salt. In this case, the DOE assumed an approximate zero strain boundary to correspond to the limits of mechanical disturbances.

7. Visual interpretations of the disturbed zone at domal salt sites (Golder Associates, Inc., 1985, Table 4-1) suggest maximum slabbing depths of 5 meters (16.4 feet), fracture depth of 6 meters (19.7 feet) spalling depths of 4.5 meters (14.8 feet), blast fractures depth of 0.6 meter (2 feet), and other excavation damage of 3 meters (9.9 feet).

8. Estimates of fracture depths of 15 meters (49 feet) by Kupfer (1980) are speculative and not substantiated by the generic data base developed by Golder Associates, Inc. (1985). In fact, telephone interviews documented by Golder Associates, Inc. (1985) state that Kupfer was not aware of any quantitative information on this subject. Kupfer (Golder Associates, Inc., 1985) believes that the old rule of thumb of fractures extending a half width of an opening is still valid. For the EA repository design, this gives a disturbed zone of 2.3 meters (7.6 feet) for CHLW and SF rooms and 2.9 (9.5 feet) meters for DHLW rooms.

9. Golder Associates, Inc. (1985, Section 4.2) discusses permeability tests from 1.5 to 8 meters (4.9 to 26.3 feet) and beyond 6 meters (19.7 feet) that suggest that fracturing has little effect at these depths, because measured permeabilities represented lower limits of testing equipment and not actual (lower) permeabilities of the salt. Consequently, even with estimates of a somewhat larger zone of mechanical disturbance, permeability measurements still indicate that it is unlikely that fluids could leave the host salt.

In summary, the DOE has estimated a mechanically disturbed zone of 15 meters and recognizes that definition of the zone of mechanical disturbance depends on the following:

- excavation method
- extraction ratio
- room size and shape

- site-specific in situ stress field
- site-specific geological structure
- site-specific mechanical properties.

Therefore, only after site characterization and design selection can the DOE estimate more reliably the extent of the disturbed zone. In addition, the notion that "significant" mechanical disturbance extends to the point of zero strain may prove to be too facile when the impact on radionuclide transport is considered. Mechanical disturbance may affect radionuclide disturbance for only much shorter distances according to field permeability tests reviewed by Golder Associates, Inc. (1985).

Chemical Effects on Transport. The introduction of oxygen, exhaust gases, microbiologic organisms, etc., onto mine surfaces during construction or operation may result in chemical changes that will influence radionuclide mobility. The potential effects of the introduction or removal of moisture from the mine by the ventilation system are also of interest. A small ground-water flux at a low velocity is projected under limiting studies (Sections 6.4.2.3.5 and 3.3.2.1; Gureghian et al., 1983, ONWI-494; D'Appolonia, 1980, ONWI-239). Radionuclide transport is expected to be controlled sufficiently by such low hydrologic fluxes, low ground-water velocities, and expected waste package performance (Section 6.4.2.3). Thus, effects of introduced chemicals on radionuclide transport are not expected to be significant.

Waste-Related Processes/Phenomenon. The thermal-mechanical effects of interest include the following:

- Thermal expansion of the rocks resulting from heat generated by the emplaced waste

- Mechanical effects of this thermal expansion coupled with potential subsidence of the overlying strata (particularly aquitards between overlying aquifers and the salt strata)

- Effects in the immediate vicinity of the repository openings, including room closure, bedding-plane slip, fracture healing, backfill consolidation, and changes in the hydrologic properties of the host rock interbeds.

These can be summarized by two basic concerns: (1) the potential for fracturing aquitards from the thermal behavior of host formations, and (2) the changes in hydrologic properties in the immediate vicinity of repository openings due to thermal-mechanical processes.

Thermal Mechanical Effects on Properties of the Rock. The potential for fracturing aquitards by thermal expansion of the host formation has been estimated in calculations performed to support the Generic Environmental Impact Statement on Commercial Waste Management and to support the International Nuclear Fuel Cycle Evaluation Studies. Most pertinent to the salt sites are analyses recently performed for Palo Duro Basin and Paradox Basin locations (Loken et al., 1984). These calculations define a tensile zone in which the tensile stress due to thermal expansion exceeds compressive forces due to the weight of the overburden. Within the elastic finite element model, thermal expansion will cause a tensile zone to exist from the Earth's surface to the depth where the weight of the overburden balances the tensile stresses due to the thermal expansion. For the Davis Canyon site, the tensile zone is estimated to extend from the surface to a depth of about 190 meters (623 feet). The top of the first aquitard, between the upper aquifer and the salt, is at a depth of about 700 to 800 meters (2,300 to 2,625 feet) (see Section 3.2.3.2). The depth to which the tensile zone is estimated to extend is well above the aquitard. The uncertainty in the depth to which the tensile zone extends is on the order of a few tens of meters. Therefore, at the Davis Canyon site, thermal expansion should not affect aquitard stability and need not be considered in defining the extent of the disturbed zone.

Various analyses and tests discussed below indicate that, with time, the hydraulic transmissivity of the backfilled openings and the zone of rock disturbed by the construction process is reduced by creep closure. These tests indicate that this process of reducing porosity and permeability is accelerated by heat and pressure.

Openings in salt at depth tend to close. For example, there are 10 years of observations reported on the Esterhazy Mine in Canada (Mraz, 1978), 20 years of measurements from Jefferson Island Mine in Louisiana (Wynn, 1965), and 5 years of data from Weeks Island Mine in Louisiana (Acres American, Inc., 1979). In all cases the openings tend to close with time, although the rate of closure is site dependent.

The process of fracture healing must be considered when determining the thermal-mechanical effects on the disturbed zone created by construction. Limited data available from laboratory testing indicate the degree and rate of healing that might be expected under repository conditions. Tests at Sandia (Costin and Wawersik, 1980, SAND80-0392) created a fracture in intact WIPP salt specimens. Then the specimens were pieced together and subjected to high temperatures (up to 100 C [212 F]) and pressures (up to 35 mPa [about 5000 psi]) to heal the fracture. The specimens were then refractured to determine the degree of healing by measuring the stress required to refracture the specimen compared with that required for original fracturing. Results indicated that up to 80 percent of original strength was attained within a few days for all conditions except the lowest temperatures and pressures. Even at 22 C (72 F) and 10 mPa (about 1450 psi), the strength of the fracture was on the order of 20 to 30 percent of the intact strength after a few days. Again, the specific data are not as important as is the indication that, as compaction of the backfill material proceeds, pressures will begin to increase. As resistance of the backfill increases, pressures will in time be attained that are sufficient at repository temperatures to begin healing any fractures in the in situ salt, thus reducing its porosity and permeability. Temperature and pressure will act to reduce the porosity and permeability of the in situ salt rather than to generate or propagate cracks.

Based on the limited testing of fracture healing mentioned above, it is concluded that fractures in the salt adjacent to a bulkhead placed in an opening in salt should be closed, if not totally healed, within a period of tens of years following bulkhead construction. The joints formed in salt should also be healed within a similar period.

In summary, thermal-mechanical effects on the hydrologic properties of the rock in the vicinity of the repository openings only reduce the potential for flow through these openings with time.

Thermal-Hydrologic Effects. A main factor that can affect the extent of the disturbed zone is the distance over which waste-generated heat affects the movement of ground water from the repository through salt. There are two distinct phenomena discussed under this topic: (1) The effect on ground-water flow caused by changes in water density and viscosity and (2) the potential for brine migration due to a thermal gradient.

Preliminary calculations using finite-element modeling quantify the effect of heat on ground-water flow through the Palo Duro Basin. The magnitude of the effect should be similar for sites in the Paradox Basin. It was assumed that porous media (Darcy) flow is an appropriate representation of ground-water movement through salt. Under these assumptions, the pre-waste-emplacement interstitial ground-water velocity in the Palo Duro salt sequence was predicted to be downward at about 2×10^{-5} meter per year for a hydraulic conductivity of 10^{-6} meter per day (0.0012 millidarcy) for the salt, and downward at about 1 by 10^{-3} meter per year for a hydraulic conductivity of 10^{-4} meters per day (0.12 millidarcy).

With heat generation equivalent to that of the conceptual repository design (Reference Repository Conditions Interface Working Group, 1983, ONWI-483, Table 2-1, p. 8) superimposed on the evaporite formation, a time-dependent flow velocity was predicted in the salt between the Yates Formation and the Lower San Andres Unit 4. However, the velocities remained small for all cases modeled. A summary of results is presented below:

Assumed Hydraulic Conductivity for Salt, m/day (md)	Steady State Interstitial Velocity (Pre-Waste Emplacement)	Interstitial Velocity (Considering Waste-Induced Heat)
10^{-4} (0.12)	Approx 1 x 10^{-3} m/yr	3 x 10^{-2} m/yr at 100 yr 1.2 x 10^{-3} m/yr at 1,000 yr 1 x 10^{-3} m/yr at 10,000 yr
10^{-6} (0.0012)	Approx 2 x 10^{-5} m/yr	1.5 x 10^{-3} m/yr at 100 yr 4 x 10^{-4} m/yr at 1,000 yr 1 x 10^{-4} m/yr at 10,000 yr

From the above data, an estimate can be made of the distance traveled by water from the vicinity of the repository toward the accessible environment while flow is influenced by the waste-induced heat. This distance reflects the potential impact of waste-induced heat on radionuclide transport. Even at a high value of hydraulic conductivity for salt (10^{-4} meter per day), the ground water is predicted to travel 10 meters (33 feet) or less from the repository in 1,000 years. In less than 10,000 years, the flow regime will have returned to near its steady state condition.

For a hydraulic conductivity of 10^{-6} meters per day (0.0012 millidarcy) (still fairly high for salt), the simulation indicates a similar distance traveled (less than 10 meters [33 feet]) before steady-state conditions return. For this lower hydraulic conductivity, the predicted velocities are lower, but the period during which heat influences the flow is longer. These two factors tend to compensate for one another resulting in a similar distance traveled while flow is influenced by waste-induced heat. Therefore, it appears that the effects of waste-generated heat on ground-water flow through salt might affect repository performance (radionuclide transport) over distances of about 10 meters (33 feet).

Brine migration due to the temperature gradient in the vicinity of the waste package affects the water content of the salt only a few meters into the salt (Section 6.4.2.3.2 and RRC-IWG, 1983, ONWI-483, pp. 17-21). The initial water movement is toward the thermal source, not away from it.

Radiation Effects. Radiation affects host salt properties only in the immediate vicinity of the waste packages, on the order of 1 meter (3.3 feet) or less into the salt (Reference RRC-IWG, 1983, ONWI-483, pp. 24-30).

Conclusion. Several processes and phenomena that could affect the rock surrounding the repository have been discussed. Results show the following estimates for disturbed zone size:

Disturbance	Range
Mechanical	less than 15 meters (49 feet) (uncertain, depending on mining parameters; site-specific data required)
Chemical	expected to be insignificant
Thermo-Mechanical	disturbance tends to close opening and heal host rock fractures
Thermal-Hydrologic	about 10 meters (33 feet)
Radiation	less than 1 meter (3.3 feet)

On the basis of this discussion, the maximum range of the disturbed zone is estimated to be about 15 meters (49 feet). There is uncertainty in this estimate for mechanical disturbances because the extent of mechanical and hydraulic effects depends on site-specific data. Therefore, this estimate may be revised when site-specific data at the repository horizon become available.

Chapter 7

COMPARATIVE EVALUATION OF NOMINATED SITES

7.1 INTRODUCTION

7.1.1 PURPOSE AND REQUIREMENTS

This chapter presents a comparative evaluation of the five sites nominated as suitable for site characterization: Davis Canyon, Deaf Smith County, Hanford, Richton Dome, and Yucca Mountain (see Figure 7-1). Each site is a preferred site within a geohydrologic setting: Davis Canyon is in the bedded salt of the Paradox Basin in Utah; Deaf Smith County is in the bedded salt of the Permian Basin in Texas; Hanford is in basalt in the Columbia Plateau in Washington; Richton is a salt dome in Mississippi; and Yucca Mountain is in tuff in the Southern Great Basin in Nevada. The process that led to the identification of these sites is described in Chapter 2.

The major objective of this chapter is to present a comparative evaluation of the sites proposed for nomination in order to satisfy the following requirements:

1. Section 112(b)(E)(iv) of the Nuclear Waste Policy Act of 1982 (the Act), which requires that a "reasonable comparative evaluation" be included in the environmental assessments that accompany site nomination.

2. Section 960.3-2-2-3 of DOE's siting guidelines (10 CFR Part 960), which requires that a reasonable comparative evaluation be made and that a summary of evaluations with respect to the qualifying condition for each guideline be provided to "allow comparisons to be made among sites on the basis of each guideline."

This comparative evaluation is intended to facilitate the comparison of the more-detailed suitability evaluations reported for each site in Chapter 6. The comparison should assist the reader in understanding the basis for the nomination of five sites as suitable for characterization (Section 112(b)(1)(A) of the Act); it is not intended to directly support the subsequent recommendation of three sites for characterization as candidate sites.

7.1.2 APPROACH AND ORGANIZATION

This comparative evaluation of the five nominated sites is based on the postclosure and the preclosure guidelines (10 CFR Part 960, Subparts B and C, respectively). The reader is referred to Chapter 6 for a detailed discussion of the structure and the content of the siting guidelines. The evaluation presented in this chapter includes both the system guidelines and the technical guidelines.

Figure 7-1. Sites selected for nomination.

The comparison of the sites against each technical guideline uses the information from the guideline evaluations presented in Chapter 6 of the five environmental assessments, whereas the comparisons against the system guidelines summarize directly the evaluations reported in Chapter 6. The approach used to compare the sites against each technical guideline is summarized below.

In order to facilitate the comparison of sites on the basis of each qualifying condition, major considerations were derived by identifying the favorable, potentially adverse, and disqualifying conditions that deal with the same general topic. Contributing factors representing site characteristics that are potentially important to each major consideration were also identified. The relative importance of the major considerations was determined primarily by the degree to which they contribute to the qualifying condition; that is, the stronger the tie between the consideration and the qualifying condition, the greater the importance of the consideration. Each site was evaluated in terms of each major consideration, taking into account the contributing factors at that site.

The purpose of identifying major considerations for each guideline is to combine closely related site conditions so that the favorable and potentially adverse conditions can be considered on balance. A major consideration may be broader in scope than the combined scope of the related favorable and potentially adverse conditions, in order for it to relate more directly to the qualifying condition. Most guidelines that contain a disqualifying condition have one or more potentially adverse conditions that are related to the disqualifying condition. Since these potentially adverse conditions are considered in the formulation of a major consideration, the important aspects of the disqualifying conditions indirectly enter the comparative evaluation. Where a major consideration that is needed to evaluate the qualifying condition does not have a related favorable or potentially adverse condition, the consideration is derived directly from the qualifying or disqualifying condition. Not all contributing factors are discussed for each site; for brevity, only the factors that contribute to the evaluation of that consideration are discussed. The evaluation of each site with respect to each major consideration is presented in alphabetical order, by site.

The major considerations for the guidelines were then considered collectively, taking into account their relative importance, in a comparative evaluation of the sites. This comparative evaluation describes the sites with the most favorable combination of characteristics first and those with a less favorable combination of characteristics last.

The comparative evaluations of the sites are summarized in Sections 7.2 and 7.3 for the postclosure and the preclosure guidelines, respectively.

7.2 COMPARISON OF THE SITES ON THE BASIS OF THE POSTCLOSURE GUIDELINES

The postclosure guidelines are concerned with the characteristics, processes, and events that may affect the performance of the repository after closure. The objective is to ensure that the health and safety of the public will be protected for thousands of years, until the radioactivity of the waste

has diminished to safe levels. This section presents a comparative evaluation of the five nominated sites against the postclosure guidelines.

7.2.1 TECHNICAL GUIDELINES

7.2.1.1 Geohydrology (postclosure)

The qualifying condition for geohydrology is as follows:

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

Major considerations

On the basis of the favorable and potentially adverse conditions for this guideline, four major considerations (see Table 7-1) are identified that influence the favorability of the site with respect to the qualifying condition. These major considerations, in decreasing order of importance, are (1) ground-water travel time and flux, (2) changes in geohydrologic processes and conditions, (3) ease of characterization and modeling, and (4) presence of suitable ground-water sources. These major considerations are, in turn, influenced by a number of more specific geologic and hydrologic properties and in situ conditions called contributing factors.

Evaluation of the sites with respect to major considerations

Ground-water travel time and flux. This consideration covers the geohydrologic conditions that control the time of ground-water travel between the disturbed zone and the accessible environment and the ground-water flux (volumetric flow rate) across or through the repository and through the host rock to the accessible environment. It is related directly to the qualifying condition as a measure of the amount of ground water that can come in contact with the waste, the amount of ground water available to transport radionuclides between the repository and the accessible environment, the time delay for these radionuclides to reach the accessible environment, and the time available for radioactive decay during transport. This major consideration is derived from the first, fourth, and fifth favorable conditions of the geohydrology guideline. It is the most important of the major considerations because transport by ground water is the primary mechanism for radionuclide movement from the repository to the accessible environment.

The contributing factors for this consideration include the hydraulic conductivity and gradient, the effective porosity, the degree of saturation, the depth to the water table, the presence of flow through fractures or porous

Table 7-1. Guideline-condition findings by major consideration--geohydrology[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: GROUND-WATER TRAVEL TIME AND FLUX					
Favorable condition 1					
Site conditions such that the pre-waste-emplacement ground-water travel time along any path of likely radionuclide travel from the disturbed zone to the accessible environment would be more than 10,000 years.	P	P	P	P	P
Favorable condition 4					
For disposal in the saturated zone, at least one of the following pre-waste-emplacement conditions exists:	P	P	P	NP	NA
(i) A host rock and immediately surrounding geohydrologic units with low hydraulic conductivities.	P	P	NP	NP	NA
(ii) A downward or predominantly horizontal hydraulic gradient in the host rock and in the immediately surrounding geohydrologic units.	NP	P	NP	NP	NA
(iii) A low hydraulic gradient in and between the host rock and the immediately surrounding geohydrologic units.	NP	NP	P	NP	NA
(iv) High effective porosity together with low hydraulic conductivity in rock units along paths of likely radionuclide travel between the host rock and the accessible environment.	NP	NP	NP	NP	NA
Favorable condition 5					
For disposal in the unsaturated zone, at least one of the following pre-waste-emplacement conditions exists:	NA	NA	NA	NA	P
(i) A low and nearly constant degree of saturation in the host rock and in the immediately surrounding geohydrologic units.	NA	NA	NA	NA	NP
(ii) A water table sufficiently below the underground facility such that the fully saturated voids continuous with the water table do not encounter the host rock.	NA	NA	NA	NA	P
(iii) A geohydrologic unit above the host rock that would divert the downward infiltration of water beyond the limits of the emplaced waste.	NA	NA	NA	NA	NP
(iv) A host rock that provides for free drainage.	NA	NA	NA	NA	P
(v) A climatic regime in which the average annual historical precipitation is a small fraction of the average annual potential evapotranspiration.	NA	NA	NA	NA	P

Table 7-1. Guideline-condition findings by major consideration—geohydrology[a,b] (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 2: CHANGES IN GEOHYDROLOGIC PROCESSES AND CONDITIONS					
Favorable condition 2					
The nature and rates of hydrologic processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years.	P	P	P	P	NP
Potentially adverse condition 1					
Expected changes in geohydrologic conditions—such as changes in the hydraulic gradient, the hydraulic conductivity, the effective porosity, and the ground-water flux through the host rock and the surrounding geohydrologic units—sufficient to significantly increase the transport of radionuclides to the accessible environment as compared with pre-waste-emplacement conditions.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 3: EASE OF CHARACTERIZING AND MODELING					
Favorable condition 3					
Sites that have stratigraphic, structural, and hydrologic features such that the geohydrologic system can be readily characterized and modeled with reasonable certainty.	NP	NP	NP	NP	NP
Potentially adverse condition 3					
The presence in the geologic setting of stratigraphic or structural features—such as dikes, sills, faults, shear zones, folds, dissolution effects, or bring pockets—if their presence could significantly contribute to the difficulty of characterizing or modeling the geohydrologic system.	P	P	P	P	P
MAJOR CONSIDERATION 4: PRESENCE OF SUITABLE GROUND-WATER SOURCES					
Potentially adverse condition 2					
The presence of ground-water sources, suitable for crop irrigation or human consumption without treatment, along ground-water-flow paths from the host rock to the accessible environment.	NP	NP	NP	NP	P

[a] Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

media, net infiltration, the extent of the disturbed zone, and the distance to the accessible environment.

At each of the sites there are uncertainties in the conceptual model of ground-water flow, including the values of the key hydraulic parameters that control ground-water travel time and flux. Taking the uncertainties into account, there are ranges of possible travel times between the disturbed zone and the accessible environment at each site. Therefore, ground-water travel time was stochastically modeled at each site, using reasonably conservative geohydrologic assumptions and ranges of hydraulic parameters. Probabilistic ranges in travel time and the statistical probability for exceeding travel times of 1,000 and 10,000 years were derived for each site. In general, the ground-water flux is expected to be low to very low at each of the sites. A summary of the evaluation for each site follows.

At Davis Canyon, ground-water travel times from the disturbed zone to the accessible environment are modeled as porous-media flow vertically and horizontally through a layered sequence of differing lithologies (salts, anhydrite, dolomite, siltstone, etc.). The calculated travel times depend on the hydraulic conductivity and the effective porosities of the varying lithologies, the thickness and continuity of each layer, and the vertical and horizontal hydraulic gradients within and between each layer. Because the values of these parameters are uncertain, the expected ground-water pathways are uncertain. To quantify this uncertainty at Davis Canyon, a computer code was developed to evaluate the probability the distribution of travel times based on distribution of hydrologic parameters derived from data collected at a DOE test well (Gibson Dome No. 1) 5 kilometers (3 miles) north of the site, various oil test wells in the Paradox Basin, and various published sources of generic data. For purposes of analyzing the ground-water travel time, the outer edge of the disturbed zone was conservatively assumed to be at the top and bottom of the host salt bed, because of uncertainty in the extent of the disturbed zone. The time required for ground water to travel through the host salt bed is not included in the calculations of pre-waste-emplacement travel time to the accessible environment. The overall regional vertical hydraulic gradient between the upper and the lower hydrostratigraphic units, separated by the evaporite section containing the host salt bed, is generally downward. However, data collected at the Gibson Dome test well indicate both local downward and upward gradients between interbeds in the evaporite section containing the proposed host salt bed. The combined vertical and horizontal gradients in the area then result in either upward-to-lateral flow or downward-to-lateral flow within the layered sequence. Both the upward-to-lateral and downward-to-lateral travel times are analyzed, resulting in quite similar distributions.

The proposed controlled-area boundary for the Davis Canyon site is limited to a distance of 1 kilometer (0.6 mile) from the edge of the disturbed zone to the accessible environment due to the proximity of Canyonlands National Park in the expected direction of ground-water flow. For a lateral distance of 1 kilometer (0.6 mile) from the outer edge of the disturbed zone to the accessible environment, downward-to-lateral travel times were stochastically analyzed through 1,000 realizations of the model. This results in a probability of .003 for travel times of less than 1,000 years and probability of a .045 for less than 10,000 years. The median travel time is 240,000 years. A distance of 5 kilometers from the edge of the repository was also analyzed in case the boundary of the controlled area should change as a

result of data developed during site characterization in a direction away from the Canyonlands National Park. This analysis results in a probability of less than 0.001 for travel times of less than 1,000 years and .006 for less than 10,000 years, with a median travel time of 880,000 years.

The Deaf Smith site is in a geohydrologic setting that is conceptually similar to that of the Davis Canyon site. A similar stochastic analysis of pre-waste-emplacement ground-water travel time was made. The computer flow model, as for Davis Canyon, consists of a series of layers representing a sequence of differing lithologies (salt, anhydrite, dolomite, siltstone, etc.), including the host salt bed. Only downward-to-lateral travel times were calculated, because only downward vertical hydraulic gradients have been observed in the vicinity of the site. The travel time was calculated beginning at the bottom of the salt repository bed (considered conservatively as the bottom edge of the disturbed zone) and extending 1 kilometer to the accessible environment. To consider the possibility that the boundary of the controlled area (and the distance to the accessible environment) might be extended, travel times were also calculated to the maximum 5-kilometer distance from the edge of the disturbed zone. The modeling is based on data obtained from literature reviews, analyses of water-well and petroleum-well records and pump testing, analyses of drill-stem tests, and analyses of laboratory tests conducted specifically for the repository program. There is a comparable level of uncertainty in the data bases for the Deaf Smith and the Davis Canyon sites. Considering porous-media flow as the likely flow mechanism, the results of travel-time analyses for an accessible environment 1 kilometer from the edge of the disturbed zone, on the basis of 1,000 realizations of the model, show a probability of .005 for travel times of less than 1,000 years and a probability of .107 for less than 10,000 years, with a median travel time of 87,000 years. For an accessible environment 5 kilometers from the edge of the disturbed zone, the probability of travel times of less than 1,000 years is less than .001, and the probability for less than 10,000 years is .015, with a median travel time of 500,000 years.

At the Hanford site, the stochastic analysis of the pre-waste-emplacement ground-water travel time used a conceptual model that is consistent with the current understanding of the deep ground-water flow system and considers the uncertainties in the hydraulic parameters used to predict travel times. In the analysis, ground-water flow is modeled along upward and lateral flow paths through an alternating sequence of basalt flows in which dense interiors of low permeability are separated by flow tops of higher permeability. The vertical and horizontal hydraulic-head gradients used in the stochastic model are deterministic; that is, they are based on quality head data obtained from piezometers at the site. The transmissivity values used in the model were based on site-specific test data that were varied over a reasonably conservative range. The range of effective porosity was estimated from geophysical logs, core samples, two tracer tests, and values reported in the literature. Key hydraulic parameters were conservatively evaluated over appreciable ranges in the model. The model considers ground-water movement that begins in the flow top immediately above the dense flow interior (the outer edge of the disturbed zone being within the dense interior host rock at an unknown distance from the flow top) of the proposed host rock and proceeds vertically upward and laterally to the accessible environment, 5 kilometers from the edge of the repository. The model conservatively does not include vertical travel time through the upper part of the undisturbed dense interior between the proposed repository and the base of the first flow top above the

repository. The range of travel times derived from the model indicates a probability of .03 or less for travel times of less than 1,000 years and a probability of .22 or less for travel times of less than 10,000 years. This compares with the shortest median travel time for the conservative analyses of 22,000 years.

At the Richton site, the accessible environment is considered to be at the flank, or periphery, of the salt stock; therefore, ground-water travel times from the disturbed zone to the accessible environment (a minimum lateral distance of 244 meters (800 feet)) are judged to be within essentially pure salt. The mechanism for ground-water movement through the salt is uncertain. Because of the ductility of salt, which reduces the likelihood of open fractures, and the extremely low matrix hydraulic conductivity and porosity, there may be little or no water movement through the salt. However, to evaluate the travel time from the edge of the disturbed zone to the accessible environment, porous-media flow was conservatively assumed to prevail in the salt. Preliminary geologic studies have not identified anomalous features that would indicate the presence of preferential permeable flow paths in the salt stock. Fracture flow is considered unlikely and is not considered in the model. Flow is assumed to obey Darcy's law, and conservative ranges of the key hydraulic parameters are used; they are based on available generic in situ and laboratory data, including geophysical well logs. No site-specific data on hydraulic parameters are available. If alternative mechanisms of movement (e.g., diffusion) are considered, the estimated travel times to the accessible environment would be several million years.

The results of the stochastic modeling show a probability of less than .001 for travel times less than 1,000 or 10,000 years to the flank of the dome. Because of the very low hydraulic conductivities measured for essentially pure salt, the calculated times of lateral travel through 244 meters (800 feet) of salt are very long. Stochastic model calculations range over six orders of magnitude--the shortest being about 50,000 years and the median about 35 million years. Although the ranges of hydraulic parameters used in the analysis are considered reasonably conservative, a great deal of uncertainty is inherent in any prediction of travel times in millions of years. Of more significance than the absolute numbers, perhaps, is that the very long travel times suggested by the analysis indicate a likelihood that little or no ground water is present or moving through an appreciably thick, undisturbed mass of salt.

At Yucca Mountain, the stochastic analysis of the pre-waste-emplacement ground-water travel time from the disturbed zone to the accessible environment computes vertical ground-water movement downward through the unsaturated zone to the water table and then 5 kilometers laterally in the saturated tuff to the accessible environment. Travel time is calculated from a horizon 50 meters (164 feet) below the proposed repository downward through a minimum of about 135 meters (443 feet) of unsaturated welded and nonwelded tuff to the water table. Most of the total travel time is through the unsaturated zone, with about 140 years estimated for the travel time through the saturated zone to the accessible environment, once the water table is reached. Uncertainty in the variability and ranges in hydraulic conductivity and effective porosity are evaluated stochastically in the model, by randomly selecting ranges in hydraulic parameters in a series of 963 vertical columns. The calculated travel times range from about 9,500 to 80,250 years. This is based on an

estimated maximum average net percolation of 0.5 millimeter per year. Ten realizations were run in each of the 963 columns of the model, with all but one of the 9,630 total realizations having a travel time of more than 10,000 years. The mean travel time in these calculations was about 43,300 years, and the median about 41,600, with a probability of about .0001 for a travel time of less than 10,000 years.

Changes in geohydrologic processes and conditions. This consideration covers the nature and rate of natural processes in the geologic setting that could ultimately change geohydrologic conditions so as to affect the ability of a repository to isolate the waste. It is directly related to the qualifying condition, which requires that geohydrologic conditions in the future be compatible with waste isolation. It is derived from the second favorable condition and the first potentially adverse condition. This consideration is second in importance because the preceding consideration, the ground-water travel time, reflects actual conditions, whereas this consideration reflects potential conditions.

Four contributing factors are identified for this consideration: climatic change, erosion, dissolution, and tectonics. On the basis of the discussion of these factors in Section 6.3.1 of each environmental assessment, it was concluded that climatic change is the only one of the four contributing factors that has a potential for significantly affecting the hydrologic system at any of the nominated sites during the next 100,000 years. Therefore, climatic change is the only potential cause of changes in the geohydrologic system that is addressed in the summary of site evaluations.

Judging from the record of the Quaternary Period in the area of the Davis Canyon site, climatic changes during pluvial conditions could increase precipitation, with a resulting increase in recharge to the ground-water system. Although it is uncertain to what extent higher rates of precipitation during the Quaternary Period have affected the hydrologic system, there is no evidence that ground-water parameters have changed significantly during the Quaternary Period. Also, the low permeability of the evaporite section separating the shallow hydrologic system from the deep confined system is expected to preclude any significant effects from expected climatic changes. Assuming that climatic changes during the next 100,000 years would be within the magnitude of past changes during the Quaternary Period, it does not appear that expected changes would adversely affect waste isolation at the Davis Canyon site during the next 100,000 years.

Judging from the record of the Quaternary Period, precipitation may be expected to increase over the current levels for the area of the Deaf Smith site, with consequent increases in recharge during the next 100,000 years. However, because of the low permeability of the evaporite section and the fine sedimentary interbeds that separate the shallow hydrologic system from the deep confined system beneath the proposed repository horizon, the variations in the nature and rates of surficial hydrologic processes that would result from future climatic changes would have little effect on the ability of a repository at the site to isolate waste during the next 100,000 years.

The climatic history of the Quaternary Period at the Hanford site indicates that any hydrologic impacts due to climatic changes would be localized or shallow phenomena (e.g., glacially induced flooding) that would

not significantly change the waste-isolation potential of the deep basalt environment during the next 100,000 years. The factors responsible for this include the low permeability of the basalt flow interiors between the land surface and the proposed repository depth; the relatively low permeability of the deep basalt flows in comparison with shallow flows and interbeds; the existence of different flow systems with depth; the short duration of floods; and the likely persistence of the arid to semiarid climate that has existed at Hanford over the past 3 million years.

For the Richton site, the Quaternary history of the region indicates that climatic changes would have no significant influence on geohydrologic conditions at the site. Variations in geohydrologic processes that have occurred in response to Quaternary climatic cycles and the associated sea-level fluctuations result in slight increases and decreases in precipitation, hydraulic gradients, and rates of ground-water movement in the geohydrologic system surrounding the salt dome. Because of the very low hydraulic conductivity of the dome salt, such slight variations in hydrologic processes are expected to have minor, if any, effects on fluid movement within the dome. Therefore, no natural geohydrologic changes that would affect waste during the next 100,000 years are expected at the site.

At Yucca Mountain, the climatic record of the Quaternary Period suggests that pluvial conditions may recur sometime during the next 100,000 years, resulting in increased net infiltration (flux) and recharge, which could in turn raise the level of the water table toward the repository. Such changes would tend to reduce the time of ground-water travel between the disturbed zone and the accessible environment and could result in some increase in the quantity of ground water coming in to contact with the waste.

Ease of characterization and modeling. This consideration addresses the complexity of the geohydrologic system in terms of whether it can be characterized and modeled with reasonable certainty. It relates to the qualifying condition because characterization is the process of collecting and analyzing the data needed to develop and perform the modeling that is the means for predicting whether the site is compatible with waste containment and isolation. This major consideration is derived from the third favorable condition and the third potentially adverse condition. Since it is not an intrinsic physical characteristic of the geohydrologic setting, this consideration is not as important as the first two considerations; however, the ability to characterize and model the geohydrologic system with reasonable certainty is essential to evaluating the geohydrologic processes and properties that affect the ability of the site to contain and isolate waste.

Some of the contributing factors that influence the ease of characterization and modeling are the presence of faults, folds, brine pockets, dissolution effects, lithologic variations, interrelationships among hydrostratigraphic units, availability of testing techniques and analytic models, and understanding of flow mechanisms.

All five nominated sites are, to varying degrees, presently judged to have geologic and hydrologic complexities that could preclude their being readily characterized or modeled with reasonable certainty. Appreciable differences exist from one site to another in present levels of uncertainty, in part because of imbalances in the quality and quantity of available data

and stages of scientific and technical investigation. A good understanding of the geohydrology of the site must be developed through the characterization process before it can be modeled with reasonable certainty. Modeling, in turn, can determine which physical characteristics need to be characterized. The difficulty of characterizing a site limits the ability to model it to an acceptable level of certainty. Although the third favorable condition is not present and the third potentially adverse condition is present at each site, it is expected that all five sites can be adequately characterized, though with varying levels of difficulty, in order to model their capabilities for long-term waste isolation to acceptable levels of certainty. A summary of the evaluation for this consideration for each site follows.

At the Davis Canyon site, the regional geologic framework and limited site-specific data suggest that the site is stratigraphically and structurally uncomplicated. Present stratigraphic information indicates that the proposed host salt bed contains minimal impurities and is a part of a reasonably well-understood sedimentary sequence. However, the present limited investigations leave many uncertainties. Structural features like faults, folds, and dissolution zones within the geologic setting could contribute to the difficulty of characterizing the system if they are found within the site. Ground-water movement through deep salt beds may be practically nil. There is a need to develop a clear understanding of the movement of fluids in salt and a site-specific ground-water hydraulics data base and to evaluate the potential for significant fracture flow in hydrogeologic units surrounding the host rock.

Because they are in similar geohydrologic settings, the Deaf Smith site and the Davis Canyon site are similar with respect to the ease of characterizing and modeling. Somewhat more data are presently available for the Deaf Smith site than for Davis Canyon, but fewer site-specific data are available for the salt sites than for the nonsalt sites. The greater number and frequency of nonsalt interbeds at Deaf Smith introduces complicating factors that are less likely to be present at Davis Canyon. As at Davis Canyon, the potential for significant fracture flow in geohydrologic units surrounding the host rock at Deaf Smith needs to be evaluated.

Generically, the horizontal distribution, variations in thickness and internal variations in the thickness of multiple basalt flows like those at Hanford may be more difficult to predict with confidence than for a sequence of sedimentary rocks like those formed at the bedded-salt sites, but site-specific investigations are more advanced at the Hanford site than at any of the salt sites. Consequently, the data base is appreciably larger and the complexities of site characterization and modeling are better defined at Hanford. Geologic features like faults, folds, internal variations in the thickness of flows, and variations in original intraflow structures known to exist in the regional setting could contribute to difficulty in modeling. Although uncertainties remain, preliminary studies have defined some basic geologic and hydrologic characteristics of the site. The existence of multiple basalt flows can complicate the characterization and modeling of the flow system, as well as provide multiple barriers to fluid movement. Accepted concepts and methods for studying saturated flow in a layered geohydrologic system are applicable to the basalt-flow system beneath Hanford. In some ways this may make characterization and modeling less complicated than at sites where applicable fluid-flow theory is either more complex or less advanced, such as for flow in salt or in the unsaturated zone at Yucca Mountain.

At the Richton site, the boundaries and dimensions of the salt stock are reasonably well defined. Limited available data on the interior characteristics of the salt stock suggest that it consists largely of pure salt that is free of significant anomalous features (e.g., large faults or clastic inclusions) that would provide important preferential ground-water flow paths. However, this concept of the dome's interior is uncertain and requires additional data for confirmation. Also, data on the surrounding geohydrologic environment mainly provide a regional picture of the ground-water flow system outside the dome, with little site-specific information to define flow relationships near the interface of the salt stock and the adjacent hydrostratigraphic units. These relationships may be complex and difficult to characterize, requiring an extensive data base that would be difficult to acquire. The characteristics of ground-water movement, if any, within salt are not well understood. Therefore, there is uncertainty in how to characterize and model fluid movement within the dome and any exchange of ground water between the dome and the surrounding geohydrologic units. On the other hand, because the accessible environment at the Richton Dome begins at the edge of the salt stock, the controlled area extends only to the periphery of the dome. The most critical part of the geohydrologic system to be characterized and modeled is confined to what may be an essentially homogeneous medium, the interior salt mass of the dome. In this respect, the flow system may be regarded as less complex and difficult to characterize and model than a system that contains a variety of lithologies or flow media between the repository and the accessible environment. However, the mechanism for ground-water flow in the salt, if such flow is significant, needs to be clearly defined during site characterization.

The geologic setting at Yucca Mountain may be considered somewhat complex, considering the structural history and volcanic origin of Yucca Mountain, and the inherent uncertainties in predicting the lateral and vertical variability of volcanic rock units. Also, the site is relatively complex from the standpoint of the availability of state-of-the-art models for measuring and analyzing flow in the unsaturated zone rather than the saturated zone. Known local faulting adds to the complexity of site characterization and modeling. However, the progress of site-specific geologic and hydrologic investigations is comparable to that at the Hanford site and more advanced than those performed at any of the salt sites. A preliminary site-specific geohydrologic data base has been established, and preliminary details of a conceptual flow model of the unsaturated zone, are defined. Advanced techniques are being developed to measure and analyze hydrologic parameters and to provide the information needed to refine models of flow in the unsaturated zone. Because of the need to develop advanced techniques and methods, the difficulty of characterizing and modeling the site with reasonable certainty may be greater than at sites in the saturated zone where currently accepted methods may be adequate for characterizing and modeling.

Presence of suitable ground-water sources. This consideration addresses the potential for radionuclides migrating from a repository to mix with ground-water sources suitable for crop irrigation or human consumption without treatment along flow paths to the accessible environment. It pertains to the qualifying condition with respect to limitations on radionuclide releases to the accessible environment and is derived from the second potentially adverse condition. This consideration is less important than the other three, because

it is unlikely that ground-water resources could be contaminated if a site is selected on the basis of its ability to isolate wastes, as reflected in the other three considerations. Of the five nominated sites, only Yucca Mountain has a finding of present for the second potentially adverse condition. A summary of the evaluation for each site follows.

At Davis Canyon a low-yielding aquifer containing good-quality ground water is present at a relatively shallow depth above the proposed repository horizon. However, ground water of good quality usable for irrigation or human consumption without treatment is not present along probable ground-water flow paths between the disturbed zone and the accessible environment. Although there is some potential for locally upward flow from the host rock, flow paths would be diverted laterally or downward at least hundreds of meters below the shallow aquifer because of the regionally downward vertical gradient below the shallow aquifer.

At the Deaf Smith site, ground-water flow is expected to be downward from the repository horizon. Water along this flow path has high total-dissolved-solids concentrations, making it unusable for crop irrigation or human consumption without treatment. There is good-quality ground water at shallow depths above the proposed repository horizon, but upward flow is not expected from the host rock.

At the Hanford site, shallow aquifers containing water of good quality exist above likely flow paths from the preferred repository horizon. However, ground water along likely flow paths between the disturbed zone and the accessible environment contains flouride, boron, and sodium concentrations considered too high for crop irrigation or human consumption without treatment.

At the Richton site, the accessible environment is considered to be at the flank of the salt stock. Therefore, ground water suitable for crop irrigation or human consumption without treatment does not occur along ground-water flow paths between the disturbed zone and the accessible environment.

At Yucca Mountain, flow paths from the disturbed zone in the unsaturated zone would be expected to be vertically downward to the water table and then laterally through the saturated zone to the accessible environment. Ground water along the flow paths in the saturated zone is of good quality and suitable for crop irrigation and human consumption without treatment.

Summary of the comparative evaluation

The Richton Dome is the most favorable of the five nominated sites for the geohydrology guideline on the basis of the four major considerations addressed under this guideline. Although site-specific data are sparse, resulting in appreciable uncertainty about flow in geohydrologic units surrounding the dome, and the mechanism of fluid flow in salt is uncertain, ground-water travel times at Richton are expected to be very long, and very little, if any, ground-water movement takes place within the salt stock. It is likely that no ground water or only very little is contained in the salt stock. Uncertainty with respect to the possible presence of anomalous features that could significantly affect flow through the dome would be addressed during site characterization. Hydrologic processes and conditions are not expected to change in a manner that would unfavorably affect the

ability of the repository to isolate waste. Modeling of the geohydrologic system surrounding the dome is expected to be difficult. The limited data base results in appreciable uncertainty about relationships between the dome and the surrounding system. However, because all pathways to the accessible environment are expected to be entirely within the salt host rock, there is a high level of certainty that no usable ground-water sources would be encountered along pathways to the accessible environment.

Davis Canyon is the next most favorable site with respect to the geohydrology guideline if it is compared to Deaf Smith on the basis of equal distances to the accessible environment. It is slightly less favorable than the Richton Dome on the first and most important major consideration and is equally favorable with the other sites on the second major consideration. The pre-waste-emplacement travel time from the disturbed zone to the accessible environment appears to be less than that at the Richton Dome, and the travel time at Davis Canyon is longer than at the Deaf Smith site for equal distances to the accessible environment at both sites. The ground-water flux through the salt host rock, as indicated by the generic understanding of the hydraulic properties of salt, may be small if not nonexistent. There is no evidence for natural geohydrologic changes that will unfavorably affect the ability of the repository to isolate the waste during the next 100,000 years. On the basis of regional geologic studies, the structure and stratigraphy of the site are considered uncomplicated, but because of uncertainties with respect to the mechanism for ground-water flow in salt and the unlikely potential occurrence of a really extensive, fracture-controlled pathways in the brittle sedimentary interbeds, the level of difficulty in characterizing and modeling the geohydrologic system with reasonable certainty is expected to be comparable with that of the other sites. No aquifers containing ground water that is usable without treatment are present along any likely ground-water pathways between the edge of the disturbed zone and the accessible environment.

The Deaf Smith site is less favorable than the Richton and the Davis Canyon sites for the geohydrology guideline when the accessible environment is equally distant from the disturbed zone at Deaf Smith and at Davis Canyon. In such a case, it is less favorable on the first and most important major consideration, but equally favorable on the second major consideration. The estimated pre-waste-emplacement ground-water travel time between the disturbed zone and the accessible environment is shorter than that at Davis Canyon and Richton. However, if the distance to the accessible environment at Deaf Smith should be lengthened up to 5 kilometers and at Davis Canyon remain at 1 kilometer, Deaf Smith would be the more favorable site with respect to the pre-waste-emplacement ground-water travel time. Although the ground-water flux within the salt host rock is expected to be low, the presence of fine clastic interbeds in the host rock results in a potential for higher flux at Deaf Smith than at Davis Canyon or Richton. No natural changes in geohydrologic conditions that would unfavorably affect the ability of the site to isolate waste during the next 100,000 years are indicated. The structure and stratigraphy of the Deaf Smith site, on the basis of regional geologic studies, are considered uncomplicated. Because of uncertainties with respect to the mechanism for ground-water flow in salt and the unlikely potential for areally extensive, fracture-controlled pathways in the brittle interbeds, the level of difficulty in characterizing and modeling the geohydrologic system is expected to be comparable with that of the other sites. Finally, there is a

high level of certainty that no aquifers containing ground water usable without treatment are present along ground-water pathways between the edge of the disturbed zone and the accessible environment.

The Hanford and the Yucca Mountain sites are both less favorable than the salt sites, but are in a comparable range of favorability with each other. Their comparative evaluations vary from one major consideration to another on the basis of available information. With respect to the pre-waste-emplacement ground-water travel time, Yucca Mountain is more favorable than the Hanford site. At Yucca Mountain, the ground-water flux through the host rock and the surrounding geohydrologic units, as indicated by the estimated maximum annual infiltration of 0.5 millimeter, is expected to be very low. A return to pluvial climatic conditions could increase the flux rate through the host rock and the surrounding geohydrologic units. This could also cause some rise in the water table toward the repository and some reduction in the time of travel to the accessible environment. Yucca Mountain and Hanford appear to have similar ranges of structural and stratigraphic complexity with unique geohydrologic complexities at each site. The complexity of fracture systems at Yucca Mountain may have important implications for characterizing and modeling flow in the unsaturated zone with reasonable certainty. Uncertainty in how to model flow in the unsaturated zone may also add to the difficulty of characterizing and modeling at Yucca Mountain. Ground-water sources of good quality are located along likely ground-water pathways from the proposed repository to the accessible environment at Yucca Mountain.

At the Hanford site, the ground-water flux through the saturated host rock and the surrounding geohydrologic units may be higher than in the unsaturated zone at Yucca Mountain. For the second major consideration, Hanford is more favorable than Yucca Mountain. Expected natural changes in hydrologic processes or geohydrologic conditions are not expected to affect the ability of a repository to isolate the waste during the next 100,000 years. Although commonly used modeling techniques may be applied, uncertainties in the structural and stratigraphic heterogeneity of the multiple basalt flows may contribute to modeling difficulties. At Hanford, no sources of ground water suitable for crop irrigation or human consumption without treatment are present along likely ground-water pathways from the edge of the disturbed zone to the accessible environment.

7.2.1.2 Geochemistry

The qualifying condition for postclosure geochemistry is as follows:

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

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-2), three major considerations are identified that influence the favorability of the site with respect to the qualifying condition are identified. In order of decreasing importance, they are (1) the expected rate of mass transfer of radionuclides from the waste package, (2) geochemical conditions that would inhibit the transport of radionuclides into the accessible environment, and (3) geochemical effects on the sorptive properties and strength of the host rock.

Evaluation of the sites in terms of the major considerations

Mass transfer of radionuclides. This consideration includes geochemical conditions in the immediate vicinity of the waste package after the permanent closure of the repository. It relates directly to the qualifying condition through the rates of radionuclide dissolution from the waste form and is based on the second and fourth favorable conditions and the first potentially adverse condition. The mass transfer of radionuclides is the most important consideration because it describes the processes by which radionuclides that are initially sealed in the solid waste form as part of the waste package will be released to the ground-water system (e.g., as ions, complexes, or particulates) or be contained within the engineered-barrier system. The most important contributing factors are the volumetric flow rate of the ground water that may contact the waste package and the chemistry of the ground water. Other contributing factors include the potential for the precipitation and sorption of radionuclides; the potential for the formation of colloids, complexes, and particulates; oxidation-reduction conditions; and the chemical reactivity of the ground water. A summary of the evaluation for each site follows.

The bedded salt of the Davis Canyon site contains little ground water. Sources of water in the repository horizon include brine inclusions and water of carnallite hydration, which constitute a small fraction of the host-rock volume. Thus, the volumetric flow rate of ground water due to the migration of these waters at the repository horizon is expected to be extremely low, if present at all. Because of their high magnesium content, the brines at Davis Canyon are potentially very corrosive for the stainless-steel container of the waste package. However, waste-package degradation should be limited because the amount of water in contact with the waste is expected to be small. The formation of some colloids will be inhibited by the high salinity of brine. Because of their high concentration in the brines, chlorides, sulfates, and carbonates could form complexes with radionuclides, which may increase the mobility of some radionuclides. Although chemically reducing conditions are expected in the host rock and the underlying aquifers, the ability of the water-rock system to maintain reducing conditions in the presence of alpha and gamma radiolysis may be limited.

The host rock at the Deaf Smith site is bedded salt that may contain more water than the rock of the other two salt sites. The salt of the lower San Andres Unit 4 contains intercrystalline muds and interbeds of mudstone containing clay; these muds and interbeds could contribute water in addition to that provided by brine inclusions. Thus, the total amount of ground water that is expected to enter the repository through brine migration should be extremely small. These brines have a high magnesium content and are

Table 7-2. Guideline-condition findings by major consideration—geochemistry[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: EXPECTED RATE OF MASS TRANSFER FROM THE WASTE-PACKAGE SUBSYSTEM					
Favorable condition 2					
Geochemical conditions that promote the precipitation, diffusion into the rock matrix, or sorption of radionuclides; inhibit the formation of particulates, colloids, inorganic complexes, or organic complexes that increase the mobility of radionuclides; or inhibit the transport of radionuclides by particulates, colloids, or complexes.	P	P	P	P	P
Favorable condition 4					
A combination of expected geochemical conditions and a volumetric flow rate of water in the host rock that would allow less than 0.001 percent per year of the total radionuclide inventory in the repository at 1,000 years to be dissolved.	P	P	P	P	P
Potentially adverse conditions 1					
Ground-water conditions in the host rock that could affect the solubility or the chemical reactivity of the engineered-barrier system to the extent that the expected repository performance could be compromised.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 2: GEOCHEMICAL CONDITIONS THAT WOULD INHIBIT RADIONUCLIDE TRANSPORT IN THE FAR FIELD					
Favorable condition 1					
The nature of rates of the geochemical processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years.	P	P	P	P	P
Favorable condition 2					
Geochemical conditions that promote the precipitation, diffusion into the rock matrix, or sorption of radionuclides; inhibit the formation of particulates, colloids, inorganic complexes, or organic complexes that increase the mobility of radionuclides; or inhibit the transport of radionuclides by particulates, colloids, or complexes.	P	P	P	P	P

Table 7-2. Guideline-condition findings by major consideration--geochemistry[a,b] (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 2: GEOCHEMICAL CONDITIONS THAT WOULD INHIBIT RADIONUCLIDE TRANSPORT IN THE FAR FIELD (Continued)					
Favorable condition 5					
Any combination of geochemical and physical retardation processes that would decrease the predicted peak cumulative releases of radionuclides to the accessible environment by a factor of 10 as compared to those predicted on the basis of ground-water travel time without such retardation.	NP	NP	P	NP	P
Potentially adverse condition 3					
Pre-waste-emplacement ground-water conditions in the host rock that are chemically oxidizing.	NP	NP	NP	NP	P
MAJOR CONSIDERATION 3: GEOCHEMICAL EFFECTS ON THE SORPTIVE PROPERTIES AND ROCK STRENGTH OF HOST ROCK					
Favorable condition 3					
Mineral assemblages that, when subjected to expected repository conditions, would remain unaltered or would alter to mineral assemblages with equal or increased capability to retard radionuclide transport.	P	P	P	P	P
Potentially adverse condition 2					
Geochemical processes or conditions that could reduce the sorption of radionuclides or degrade the rock strength.	NP	NP	NP	NP	NP

[a] Key: NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

potentially very corrosive to the stainless-steel container of the waste packages, but the small amount of water expected in the repository will limit waste-package degradation. The formation of some, but not all, colloids will be inhibited by the high salinity of brine. Because of their high concentrations in the brine, chlorides, sulfates, and carbonates could form complexes with radionuclides, which may increase the mobility of some radionuclides. While chemically reducing conditions are expected in the host rock and underlying aquifers, the ability of the water-rock system to maintain reducing conditions in the presence of alpha and gamma radiolysis may be limited.

The Hanford site may have a somewhat higher flow rate of water past the waste package than other sites. The bentonite and crushed-basalt packing material that will surround the low-carbon-steel disposal containers is expected to significantly reduce the flow rate of ground water that could come in contact with the waste. The ground water at Hanford has a low salinity in comparison with the salt sites and a high pH, which tends to reduce the rates of container corrosion. In addition, the chemically reducing conditions that are expected would lower the solubility of redox-sensitive radionuclides and further lower the rates of container corrosion. However, alpha and gamma radiolysis may result in localized oxidizing conditions around the disposal container. Ground water at the repository level contains carbonate and hydroxyl ions, which could complex with escaping radionuclides, thereby increasing their mobility. Interactions between the waste package and ground water may result in the precipitation of iron-silica that would tend to scavenge radionuclides. In addition, sorption is expected to play a major role in the retardation of radionuclide transport.

Richton Dome is probably driest of the salt sites because of the small quantity of brine inclusions typical of domed salt. The volumetric flow rate of ground water at the repository horizon from brine migration is expected to be extremely low. As a result, waste-package degradation should be limited in spite of the inherently corrosive nature of brine. The formation of some, but not all, colloids should be inhibited by the high salinity of brine. The chloride and sulfate present in the brine could form complex with, and thus increase the mobility of, some radionuclides. While chemically reducing conditions are expected in the host rock, the ability of the water-rock system to maintain reducing conditions in the presence of alpha and gamma radiolysis may be limited.

The Yucca Mountain site is in a geologic environment with a very low ground-water flux through the candidate repository horizon. The low salinity and the nearly-neutral pH of the ground water would tend to reduce the corrosion rate of the disposal container; however, the ground water is oxidizing and would tend to make the waste-package environment somewhat more corrosive than water with lower oxidation-reduction (redox) conditions. The potential for the formation of inorganic complexes in the ground water of the Yucca Mountain site is probably low because of the very low salinity of the water, although the carbonate present in the ground water may increase the mobility of some radionuclides. The nearly-neutral pH of the water is conducive to the low solubility of oxides and hydroxides of some radionuclides, especially the actinides. In addition, interactions between the waste package and ground water may result in the precipitation of iron-silica, which would tend to scavenge radionuclides.

Radionuclide transport. This major consideration relates directly to the qualifying condition with respect to the natural barriers that would inhibit the transport of radionuclides into the accessible environment; it is based on the first, second, and fifth favorable conditions and the third potentially adverse condition. The contributing factors that are the most important for the quantitative evaluation of radionuclide transport and retardation include sorption and precipitation as well as redox conditions. A summary of the evaluation for each site follows.

At the Davis Canyon site, the geochemical processes within the host rock are not expected to be altered by anything other than the dissolution of the host salt, and available data suggest that dissolution will not be a problem at Davis Canyon. The salt contains very small amounts of clay minerals that could enhance the sorption of migrating radionuclides. Conversely, the high ionic strength of the brine would tend to decrease the sorptive capacity of these clays. Redox conditions in the interbeds within the salt cycles and in the aquifer beneath the salt of the Paradox Formation are reducing, which decreases the solubility of some key redox-sensitive radionuclides. However, the chloride and carbonate, which are present in the brines in high concentration, could form complexes with radionuclides, and this may increase the mobility of these radionuclides. However, sulfate solubility relationships may limit the concentrations of some radionuclides.

At the Deaf Smith site, geochemical processes would not be expected to be altered by anything other than the dissolution of the host salt, and dissolution is not expected to be a problem at the site. The salt of the Deaf Smith site contains numerous mudstone inclusions and interbeds, and approximately half of them are composed of clay and clay-sized particles. Although it is possible that the clay could increase the sorption of migrating radionuclides, the high ionic strength of the brine tends to decrease the sorptive capacity of the clay. Ground water in the aquifer that underlies the salt cycles of the Palo Duro Basin is reducing, which further decreases the solubility of some key redox-sensitive radionuclides. However, the chloride and carbonate present in the brine could form complexes with radionuclides, thereby increasing their mobility. However, sulfate solubility relationships may limit the concentrations of some radionuclides.

At the Hanford site, little change is expected in the geochemical processes within the basalts because of the depth and the saturation of the repository horizon. The dense interior of the host rock should afford some degree of physical retardation for radionuclides. The geochemical environment of the site is favorable for the precipitation and sorption of radionuclides (i.e., reducing ground water and abundant secondary clays and zeolites from lining fracture and fragment surfaces). The secondary mineral assemblages that would be formed are believed to be stable under the temperatures expected in the disturbed zone. Since the data on colloids, particulates, and organics are limited, these factors cannot be fully evaluated at present. The ground water is of low salinity, but it contains carbonate and hydroxyl ions that could form complexes with radionuclides.

At the Richton site, the geochemical processes within the host rock would not be expected to be altered by anything other than dissolution. Available data suggest that dissolution should not be a problem at the site. The salt of the Richton Dome is predominantly halite with a very low water content.

Available data suggest that the water contained in fluid inclusions in the salt is reducing and should decrease the solubility of some redox-sensitive radionuclides. Because of their high concentrations, the chloride, sulfate, and carbonate present in the brines could form complexes with radionuclides, thereby increasing their mobility. However, sulfate solubility relationships may limit the concentration of some radionuclides.

At Yucca Mountain, little water is expected to pass through the tuff. The predominant mode of water migration is currently thought to be matrix flow along much of the ground-water-flow path. Sorption and diffusion are expected to delay or retard the migration of radionuclides. The oxidizing nature of the water may inhibit radionuclide precipitation and sorption for redox-sensitive radionuclides. The abundance of highly sorptive secondary clays and zeolites along ground-water-flow paths should provide a sorptive barrier to most radionuclides. Redox-sensitive radionuclides like technetium may not be retarded by sorption. The low salinity of the ground water would be conducive to the formation of some colloids since certain actinides form colloids in dilute nearly-neutral waters. Since the data on colloids, particulates, and organics are limited, these factors, cannot be fully evaluated at present.

Sorption and rock strength. This consideration addresses geochemical processes that could adversely affect the sorptive capacity or strength of the host rock, or both. The consideration relates directly to the qualifying condition with respect to the retardation of radionuclides by natural barriers in the repository and along ground-water-flow paths to the accessible environment; it is derived from the third favorable condition and the second potentially adverse condition. Sorption and rock strength are considered less important that the preceding considerations because they would affect only a small percentage of the total rock mass surrounding the repository. Change in the sorptive capacity of the host rock minerals is the most important contributing factor under this consideration because of the potential effect on the retardation of radionuclides. The major contributing factors for this consideration are the stability of mineral assemblages, the effects of mineral alteration on sorption, and the effects of mineral alteration on rock strength. A summary of the evaluation for each site follows.

The mineral assemblage at the Davis Canyon site may contain carnallite, which could dehydrate when subjected to repository heat and release magnesium-rich brines. High-magnesium brines would accelerate the degradation of the waste packages and subsequently lead to a release of radionuclides. In addition, alteration of the carnallite could reduce the strength of the host rock. However, the quantity of carnallite at the Davis Canyon site is expected to be small, and carnallite should have little effect on radionuclide containment.

The mineral assemblage at the Deaf Smith site includes interbeds and inclusions of mudstone. It is assumed that these consist of approximately 50 percent clay minerals that may dehydrate under the geochemical conditions within the repository. However, because of the small volume of clay minerals, the alteration of these materials is not expected to affect the retardation of radionuclides or the strength of the host rock.

The host rock at the Hanford site consists of basalt and a number of sorptive secondary minerals (e.g., clays, zeolites). Laboratory tests suggest that repository conditions may result in the formation of a mineral assemblage similar to the secondary minerals formed naturally in basalt as a result of hydrothermal alteration. Although the hydrothermal conditions near the repository could adversely affect the sorptive capacity of some of these minerals, there is abundant evidence that hydrothermal conditions could alter the volcanic materials to more sorptive materials (e.g., clays and zeolites). In general, the effects of the repository on rock strength are expected to be negligible.

At the Richton site, the mineral assemblage consists mainly of halite with some anhydrite. Because of the stability of the minerals at this site, it is expected that no geochemical alteration or reduction in rock strength would affect the transport of radionuclides.

The mineral assemblage in the host rock of the Yucca Mountain site consists of 98 percent quartz, feldspar, and cristobalite, with small amounts of secondary clays and zeolites. The sorptive capacity of the host rock is likely to be slightly reduced by the dehydration of clays and zeolites in the disturbed zone and remain unaffected in the surrounding rocks. Only very small amounts of volcanic glass are likely to be present. Rock strength is not expected to be affected by the geochemical conditions in the repository.

Summary of comparative evaluations

Hanford and Yucca Mountain are the most favorable sites for the geochemistry guideline. These two sites are expected to have the most favorable geochemical conditions with respect to the waste package and radionuclide retardation. The basalt at Hanford should respond favorably to geochemical conditions in the repository by creating additional sorptive capacity. Hanford also has more favorable redox conditions. Yucca Mountain has unsaturated conditions as well as the additional radionuclide-retardation effects of matrix diffusion.

The Davis Canyon, the Deaf Smith, and the Richton sites are favorable for all major considerations and are essentially equivalent with respect to the geochemistry guideline. They are less favorable than the nonsalt sites because the sorptive capacity of salt is very limited and the brines at these three sites could reduce the lifetime of the waste package. Moreover, the geochemical conditions in the salt sites are not expected to enhance the retardation of radionuclides through the alteration of the host rock to the degree that is expected at Hanford. The amount of brine, however, will probably be small, and the transport of radionuclides by this brine is likely to be quite limited. Therefore retardation due to geochemical effects may be of limited importance.

7.2.1.3 Rock characteristics (postclosure)

The qualifying condition for postclosure rock characteristics is as follows:

> The present and expected characteristics of the host rock and surrounding units shall be capable of accommodating the thermal, chemical, mechanical, and radiation stresses expected to be induced by repository construction, operation, and closure and by expected interactions among the waste, host rock, ground water, and engineered components. The characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in §960.4-1 for radionuclide releases to the accessible environment and (2) the requirements set forth in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-3), three major considerations are identified that influence the favorability of the sites with respect to the qualifying condition. In order of decreasing importance, they are (1) the potential effects of repository-induced heat on waste containment or isolation, (2) the complexity of engineering measures required to ensure waste containment and isolation, and (3) flexibility for locating the underground facility to ensure waste isolation. These major considerations are, in turn, influenced by a number of more-specific rock properties and in situ conditions.

Evaluation of the sites in terms of the major considerations

Effects of repository-induced heat. This consideration is derived from the second favorable condition and second and third potentially adverse conditions. The factors contributing to this condition are the thermal properties of the host rock, such as thermal conductivity and the coefficient of thermal expansion; mechanical properties, such as a sufficiently high ductility for fractures to heal; thermomechanical behavior, such as the potential for thermally induced fractures; and geochemical conditions, such as the potential for brine migration and the hydration or dehydration of mineral components. This consideration also takes into account the effect of repository-induced heat on the integrity of the host rock and the surrounding rock units. Because of the potential effects of these factors on waste isolation, this major consideration is more important than the other two. A summary of the evaluation for each site follows.

At Davis Canyon, the effect of repository-induced temperature increases after closure can be favorable because of increases in the rate of salt creep, which would seal the underground openings and reconsolidate and recrystallize the salt backfill. Adverse impacts from a temperature increase would include the migration of brine within the host rock to the heat source and an increase in gas pressure if brines or gases are present in significant quantities. Limited site-specific data indicate very little brine is present at Davis Canyon. The adverse geochemical impacts from a temperature increase could also include mineral alteration and the dehydration of carnallite, but test

Table 7-3. Guideline-condition findings by major consideration—rock characteristics (postclosure)[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: POTENTIAL IMPACT OF REPOSITORY-INDUCED HEAT ON WASTE CONTAINMENT OR ISOLATION					
Favorable condition 2					
A host rock with a high thermal conductivity, a low coefficient of thermal expansion, or sufficient ductility to seal fractures induced by repository construction, operation, or closure or by interactions among the waste, host rock, ground water, and engineered components.	P	P	P	P	P
Potentially adverse condition 2					
Potential for such phenomena as thermally induced fractures, the hydration or dehydration of mineral components, brine migration, or other physical, chemical, or radiation-related phenomena that could be expected to affect waste containment or isolation.	P	P	NP	P	NP
Potentially adverse condition 3					
A combination of geologic structure, structure, geochemical and thermal properties, and hydrologic conditions in the host rock and surrounding units such that the heat generated by the waste could significantly decrease the isolation provided by the host rock as compared with pre-waste-emplacement conditions.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 2: COMPLEXITY OF ENGINEERING MEASURES REQUIRED TO ENSURE WASTE CONTAINMENT AND ISOLATION					
Potentially adverse condition 1					
Rock conditions that could require engineering measures beyond reasonably available technology for the construction, operation, and closure of the repository, if such measures are necessary to ensure waste containment or isolation.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 3: SIGNIFICANT FLEXIBILITY IN HOST-ROCK DIMENSIONS TO ENSURE ISOLATION					
Favorable condition 1					
A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the underground facility to ensure isolation.	P	NP	NP	P	NP

[a] Key: NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

results to date indicate that impacts from alteration or dehydration are not significant if the carnallite is under confining pressure.

At the Deaf Smith site, repository-induced temperature increases in the salt would contribute to creep effects like those at Davis Canyon. The rate of salt creep is expected to be higher at the Deaf Smith site than at Davis Canyon. The potential for creep-related disturbances to the interbeds and aquifers above the repository adds complexity at the Deaf Smith site.

At the Hanford site, repository-induced temperature increases may alter the permeability of the rock mass, through changes in fractures. It will also increase the in situ stresses in the vicinity of the excavations, possibly resulting in a readjustment of the rock mass and alterations in the local hydrologic regime. The rates of hydrochemical reactions among the various components will increase with the addition of heat. This is expected to have a positive effect on the isolation capabilities of the Hanford site.

At the Richton site, the effect of the repository-induced temperature increase on salt creep is expected to enhance the isolation capability of the site. The rate of salt creep at the Richton Dome is expected to be similar to that at the Deaf Smith site. The absence of stratification and the higher purity of the salt at Richton Dome should result in a less-anisotropic mechanical response to the temperature increase. The Richton Dome has a low brine content, and therefore minimal effects from brine migration are expected. Thermally induced uplift could affect the caprock (gypsum) over the dome, but modeling results indicate that such uplift is not expected to adversely affect the isolation capability of this site.

At Yucca Mountain, the problems associated with repository-induced heat are negligible, primarily because the underground facilities are in the unsaturated zone. The thermal pulse will modify the permeability of existing fractures since thermal expansion decreases the permeability of the rock mass, which in turn reduces the potential for new fractures. The Yucca Mountain site has some rock-mass heterogeneities that could cause an undetermined, but probably not adverse, response to heat (from both the variability of the content of lithophysae and the regions in which the tuff has been welded to different degrees). Although only preliminary measurements from surrounding strata are available, the rock stresses are not expected to be increased to unacceptable levels by the thermal response.

Complexity of engineering measures. This consideration includes in situ characteristics and conditions that could require engineering measures beyond reasonably available technology to ensure waste containment and isolation. Engineering measures relate directly to the qualifying condition through the specification that reasonably available technology is to be used to meet the requirements of the engineered-barrier system. It is derived from the first potentially adverse condition. The major contributing factors to this consideration are the uncertainty about the durability of man-made sealing material after closure and the effects of the in situ environment on engineered-barrier performance (e.g., the effects of brine on the disposal container). Complexity of engineering methods is considered less important than repository-induced heat effects because of the greater potential of heat effects to impair the isolation capabilities of the site. A summary of the evaluation for each site follows.

The sealing of boreholes and shafts at Davis Canyon is not expected to require complex engineering methods. The processes of sealing a repository in salt can be accomplished with technology developed in the salt-mining industry. With regard to interactions between the waste and the host rock, brines at Davis Canyon, if present, could accelerate the corrosion of the waste package.

Like Davis Canyon, the Deaf Smith site is not expected to require complex engineering methods. The site is expected to require particularly careful sealing to isolate the shaft from the Ogallala aquifer. The repository can be sealed by technology developed in the salt-mining industry from experience in drilling in the Palo Duro Basin. Interactions between the brine that may be present and the waste packages could accelerate the corrosion of the waste package, which could diminish the containment capabilities of the engineered-barrier system.

The ability to properly seal shafts and boreholes in basalt and to confirm the long-term effectiveness of seals are major concerns at Hanford. In particular, the sealing of the overlying aquifers from the repository horizon will require additional engineering measures to effectively isolate the waste. With regard to interactions of the various components of the engineered-barrier system, the expected presence of a geochemically reducing environment after closure and the sorptive properties of the secondary minerals formed in fractures in basalt are likely to enhance the containment and isolation capability at Hanford.

At the Richton site, shafts through the overlying saturated sediments and the caprock can be sealed by using technology similar to that used in mines in other salt domes. The sealing of the repository is not expected to require complex engineering measures. Interactions between the brine that may be present in the Richton Dome and the waste package could accelerate the corrosion of the waste package, which could diminish the containment capabilities of the engineered-barrier system.

At Yucca Mountain, the host rock is unsaturated; furthermore, construction experience at the Nevada Test Site shows that technology for borehole and shaft seals is readily available. In addition, since the seals will be required to perform only as well as the overall rock-mass permeability, long-term seal performance requirements are not particularly demanding. With regard to the interactions of the various components of the engineered-barrier system, the expected rock and geochemical conditions are favorable.

Flexibility. This consideration pertains to flexibility in determining the depth, configuration, and location of the underground repository. It relates to the qualifying condition because flexibility in locating the repository at a site increases the favorability of the site with respect to the qualifying condition. Added flexibility in locating the repository will help avoid geologic features or anomalies that could adversely affect the isolation capabilities of the site. Even after requirements for preclosure flexibility have been satisfied, added flexibility may still be necessary to satisfy this postclosure consideration in terms of the depth of excavations, the orientations of drifts and their intersections, and the location of

seals. A greater volume of host rock could provide isolation capability over and above the degree deemed minimally acceptable. On this basis, the contribution of flexibility to waste isolation is less than that of the other two considerations for this guideline. A summary of the evaluation for each site follows.

The host rock at Davis Canyon is expected to offer significant flexibility in that the available thickness appears to be several times greater than the required thickness. In addition, the potential host rock extends laterally underground for many kilometers. The presence of significant interbeds, impurities, gases, and structural features and their potential for adverse effects on flexibility are not yet well defined at this site.

At the Deaf Smith site, numerous interbeds may limit the vertical flexibility of locating a repository with respect to isolation considerations. In contrast, the host rock is expected to extend laterally for a considerable distance. The presence of impurities, brines, gases, and structural features and their potential to adversely affect flexibility are not yet well defined.

The Hanford site appears to offer restricted vertical but extensive horizontal flexibility with respect to isolation considerations. The thickness of the basalt can vary significantly over short distances, and the predictability of host-rock thickness is considered to be uncertain because of a limited data base.

The Richton site provides significant vertical flexibility and adequate lateral flexibility. Unfavorable internal structures within the salt dome could be encountered during site characterization; if present, they would diminish the flexibility for locating underground facilities at this site.

The host rock at Yucca Mountain offers significant vertical flexibility, but lateral flexibility is restricted by minor faults, shallow overburden, or site anomalies. The lateral homogeneity of the potential host rock outside the primary repository area has not been established.

Summary of comparative evaluation

Yucca Mountain is the most favorable site on the basis of the two most important considerations. It is expected that the response of the host rock to the heat loading of the repository would have an overall favorable effect. Furthermore, the long-term seal-performance requirements at Yucca Mountain are not expected to be very demanding. Although the flexibility for locating the underground facility is limited at Yucca Mountain, this does not outweigh the favorability of the other more important considerations.

The Davis Canyon and the Richton sites are next in favorability for the rock-characteristics guideline. At Davis Canyon, the repository-induced temperature increase is expected to improve the performance of the site by increasing the rate of salt creep, which would seal the underground openings by reconsolidating the salt backfill. However, the impact of the brine migration toward the heat source needs to be assessed. The sealing of

boreholes and shafts at Davis Canyon is not expected to require complex engineering methods. Davis Canyon is also expected to offer significant flexibility in locating the repository because of its lower brine content. The Richton site is more favorable than Davis Canyon for the repository-induced heat consideration. Richton is less favorable than Davis Canyon and Yucca Mountain on the basis of the major consideration for the complexity of engineering methods because of potential problems with sealing the repository from the overlying sediments and caprock. The Davis Canyon and the Richton sites are equally favorable with respect to host-rock flexibility. On the basis of these comparisons, Davis Canyon and Richton are approximately equal in favorability under this guideline.

Hanford is somewhat less favorable than the Yucca Mountain, the Davis Canyon, and the Richton sites for this guideline. Although Hanford is very favorable with respect to the effects of repository-induced heat, it may require complex engineering methods because of potential difficulties in sealing the overlying aquifers from the repository horizon. There has been little experience in sealing hard-rock mines to the degree that will be required for the repository. Hanford also appears to offer restricted vertical flexibility with respect to isolation considerations.

The Deaf Smith site is considered to be somewhat less favorable with regard to the rock-characteristics guideline. It is the least favorable site for the major consideration of repository-induced heat because of more-extensive interbeds. It is also the least favorable site under the third major consideration because the presence of interbeds limits its vertical flexibility. However, these considerations are not likely to significantly affect the ability of the site to contain or isolate waste.

7.2.1.4 Climatic changes

The qualifying condition for the climatic changes guideline is as follows:

> The site shall be located where future climatic conditions will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in §960.4-1. In predicting the likely future climatic conditions at a site, the DOE will consider the global, regional, and site climatic patterns during the Quaternary Period, considering the geomorphic evidence of the climatic conditions in the geologic setting.

Major consideration

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-4), one major consideration is identified that influences the favorability of the sites with respect to the qualifying condition: the effect of future climatic changes on the ability of the site to isolate waste. Contributing factors include Quaternary climatic cycles and the in situ conditions at a site. The major consideration is directly related to the qualifying condition through the consideration of

Table 7-4. Guideline-condition findings by major consideration--climatic change[a,b]

Condition[c]	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
Favorable condition 1					
A surface-water system such that expected climatic cycles over the next 100,000 years would not adversely affect waste isolation.	P	P	P	P	P
Favorable condition 2					
A geologic setting in which climatic changes have had little effect on the hydrologic system throughout the Quaternary Period.	NP	NP	NP	NP	NP
Potentially adverse condition 1					
Evidence that the water table could rise sufficiently over the next 10,000 years to saturate the underground facility in a previously unsaturated host rock.	NA	NA	NA	NA	NP
Potentially adverse condition 2					
Evidence that climatic changes over the next 10,000 years could cause perturbations in the hydraulic gradient, the hydraulic conductivity, the effective porosity, or the ground-water flux through the host rock and the surrounding geohydrologic units, sufficient to significantly increase the transport of radionuclides to the accessible environment.	NP	NP	NP	NP	NP

[a] Key: NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

[c] All the conditions in this table are associated with one major consideration: the effect of climatic changes on the ability of the site to isolate the waste.

climatic changes that may affect waste isolation. It is derived from the two favorable conditions and the two potentially adverse conditions. A summary of the evaluation for each site follows.

Evaluation of sites with respect to the major consideration

At the Davis Canyon site, climatic changes during the Quaternary Period are thought to have increased precipitation by as much as 120 percent. Increased precipitation during the Pleistocene may have increased recharge rates and flow through hydrostratigraphic units as well as rates of erosion and dissolution. Estimates of increased precipitation are based on regional data that cover the last 13,000 years and site-specific geomorphic data. Although it is uncertain by how much increased precipitation affected the hydrologic system, it does not appear that changes of the same magnitude would adversely affect waste isolation. To establish bounding cases for the potential effects of increased precipitation on the hydrologic system, a simple worst-case assumption was made in which increased precipitation raises the water table to the ground surface in the Abajo Mountains. The resulting hydraulic gradient between the Abajo Mountains and the Colorado River is not significantly greater than the present maximum apparent hydraulic gradient estimated from hydrologic tests. Preliminary estimates of the rates of erosion and dissolution during the Quaternary Period, if projected into the future, would not affect the isolation capability of the host rock, because no significant changes in flow parameters, such as porosity or permeability, have been identified in the Quaternary Period. Preliminary estimates of the maximum rates of incision over the next 100,000 years are approximately 40 meters (132 feet). Although increased rates of incision may alter the surface-water system, increased incision at the surface is not expected to affect the integrity of a repository at a depth of 885 meters (2,900 feet).

At the Deaf Smith site, regional data indicate that lower temperatures and increased effective moisture occurred during the Pleistocene. The Quaternary record suggests cyclical increases in precipitation during pluvial cycles. Increases in precipitation during future pluvial conditions would increase surface-water ponding and growth of vegetation. The increased vegetation would tend to decrease the rates of erosion, though localized increases in erosion could occur near escarpments. Although these climatic changes would change the surface-water system, they are not expected to reduce the waste-isolation capabilities of the host rock. Potential effects of Quaternary climatic cycles on the hydrologic system include changes in the rates of recharge and increased rates of dissolution at salt margins. Increased recharge to the upper hydrostratigraphic unit would result in an increase in the hydrologic gradient between this unit and the underlying units, but models of this process show no significant effect in the underlying units for more than 10,000 years. Although the data are insufficient to quantify the effects of these changes on the hydrologic system, there is no evidence to suggest that Quaternary climatic changes had a significant effect on the ground-water system.

At the Hanford site, if glacially induced catastrophic floods recurred, they would alter the present surface-water system by increasing runoff, the rates of erosion, and ponding. The net effect of catastrophic flooding would be sediment aggradation. These changes in the surface-water system would be short-lived and are not expected to significantly affect the confined aquifers

of the Grande Ronde basalts. If glaciation were to recur, the major adverse effects would be increased recharge from meltwater and catastrophic flooding. Increased recharge may be expected to cause some rise in the potentiometric surfaces of shallow aquifer systems, but the transient nature of increased recharge is such that significant long-term effects on the confined aquifers of the Grande Ronde basalts are not expected.

For the Richton site, the data are insufficient to quantify the effects of future climatic changes on the surface-water system. However, regional data suggest that, if the climate returned to a glacial maximum, increased precipitation would slightly increase erosion and ground-water recharge. During the late Wisconsinian glaciation, the sea level in the Gulf of Mexico was 100 to 130 meters (330 to 430 feet) below the present mean sea level. This regional change in base level, combined with regional uplift, resulted in stream entrenchment. Geomorphic evidence in the region suggests that stream entrenchment in major rivers was on the order of 30 meters (100 feet). This would have little effect on the deep confined ground-water system around the Richton Dome. A future interglacial cycle accompanied by a melting of the ice sheets equivalent to Pleistocene interglacials could cause a rise in sea level of 5 to 10 meters (16 to 32 feet). An equivalent rise in sea level would not inundate the surface of the site, which is at least 50 meters (164 feet) above the mean sea level. Thus, the analysis of regional data suggests that future climatic changes would not affect the surface-water or the ground-water systems to the extent that the isolation capabilities of the site would be affected.

Analysis of data on the effects of climate changes in the vicinity of Yucca Mountain suggests that surface-water systems changed little during the Quaternary Period and are not expected to change significantly in the next 10,000 years. The present surface-water system was established by early Quaternary time. It is unlikely that the maximum probable climatic change, from arid to semiarid conditions, would cause a significant change in the present drainage system. Climatic data suggest that Quaternary climatic changes had the following effects on the ground-water system: increased recharge; increased elevation of, and gradients in, the water table; and upgrade shifts in discharge points. Data from the region suggest that the effects of these changes were minor. One exception may be the effect of increased recharge on the hydrologic system, though the magnitude of the increased recharge has not yet been quantified.

If pluvial conditions were to occur, increased recharge may have a significant effect on the ground-water flux and may raise the level of the water table. Preliminary modeling of increases in the water table during a full pluvial cycle, assuming a 100-percent increase in precipitation, suggests a maximum rise of 130 meters (427 feet). Such a rise in the water table would not saturate the repository. Furthermore, considering the various sources of uncertainty in the model--such as the method used to simulate recharge, the assumption that the response of the water table is instantaneous, and the use of a two-dimensional model to simulate three-dimensional flow--the prediction of a 130-meter rise in the water table is uncertain and may not be realistic. It is unlikely that increased recharge from a return to pluvial conditions would significantly increase radionuclide transport to the assessible environment.

Summary of the comparative evaluation

The available data suggest that the Davis Canyon, Deaf Smith, Hanford, and Richton sites are equally favorable with respect to the major consideration and the guideline on climatic changes. At these sites changes in the surface-water system over the next 100,000 years are not expected to adversely affect isolation capabilities. Climatic changes during the Quaternary Period may have had minor effects on the ground-water systems. In the next 10,000 years, none of these sites is expected to undergo climatic changes that would decrease the ability of the natural barriers to isolate the waste.

The Yucca Mountain site is less favorable than the other sites because future climatic changes may produce a significant increase in recharge to the geohydrologic system. Assuming an eventual return to pluvial conditions, preliminary modeling suggests that increased recharge may increase the ground-water flux, decrease the ground-water travel time, and increase the elevation of the water table. The potentially increased flux, combined with a substantial rise in the water table, introduces greater uncertainty in assessing the potential effects of future climatic changes on the Yucca Mountain site. However, climatic conditions during the next 10,000 years would not be likely to significantly increase radionuclide releases to the accessible environment.

7.2.1.5 Erosion

The qualifying condition for erosion is as follows:

> The site shall allow the underground facility to be placed at a depth such that erosional processes acting upon the surface will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in §960.4-1. In predicting the likelihood of potentially disruptive erosional processes the DOE will consider the climatic, tectonic, and geomorphic evidence of rates and patterns of erosion in the geologic setting during the Quaternary Period.

Major consideration

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-5), one major consideration is identified that influences the favorability of the sites with respect to the qualifying condition: the effects of erosional processes on waste isolation. The major consideration is derived from the three favorable conditions and the two potentially adverse conditions and evaluates effects of erosional processes on waste isolation. It is directly related to the qualifying condition through emphasis on the ability to isolate waste.

Table 7-5. Guideline-condition findings by major consideration--erosion[a,b]

Condition[c]	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
Favorable condition 1					
Site conditions that permit the emplacement of waste at a depth of least 300 meters (984 feet)below the directly overly ground surface.	P	P	P	P	NP
Favorable condition 2					
A geologic setting where the nature and rates of the erosional processes that have been operating during the Quaternary Period are predicted to have less than 1 chance in 10,000 over the next 10,000 years of leading to releases of radionuclides to the accessible environment.	P	P	P	P	P
Favorable condition 3					
Site conditions such that waste exhumation would not be expected to occur during the first 1 million years after repository closure.	P	P	P	P	P
Potentially adverse condition 1					
A geologic setting that shows evidence of extreme erosion during the Quaternary Period.	NP	NP	NP	NP	NP
Potentially adverse condition 2					
A geologic setting where the nature and rates of geomorphic processes that have been operating during the Quaternary Period could, during the first 10,000 years after closure, adversely affect the ability of the geologic repository to isolate the waste.	NP	NP	NP	NP	NP

[a] Key: NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

[c] All of the conditions in this table are associated with one major consideration: effects of erosional processes on waste isolation.

Contributing factors include the depth of waste emplacement, evidence of extreme erosion during the Quaternary Period, the potential for uncovering the waste, and the assessment of future erosion rates and geomorphic processes on the basis of the climatic, tectonic, and geomorphic evidence of erosion rates and patterns during the Quaternary Period. These factors cannot be evaluated individually to make a judgment on the qualifying condition; they must be evaluated together. It is for this reason that only one major consideration is identified. A summary of the evaluation for each site follows.

Evaluation of sites in terms of the major consideration

At Davis Canyon, the host-rock unit (salt cycle 6) is estimated to occur at a depth of approximately 885 meters (2,900 feet). During the Quaternary Period, erosion in the candidate area has been almost continuous, though long-term rates of incision are not thought to be extreme. Stream erosion is predicted to erode no more than approximately 3 meters (12 feet) below the present ground surface in 10,000 years. Streams in the region have been predicted to erode up to 240 meters (800 feet) into their present channels (using long-term incision rates) during the first million years after repository closure. The Quaternary geologic record indicates that geomorphic processes should not adversely affect the ability of the repository to isolate the waste. This includes a preliminary assessment of the eastward propagation of the graben systems west of the site. Considering the planned depth of the repository, present knowledge suggests that it is highly unlikely that erosion will lead to releases of radionuclides to the accessible environment in the next 10,000 years.

At the Deaf Smith site, the host rock is in Unit 4 of the Lower San Andres Formation, where the top of the unit is 700 to 760 meters (2,300 to 2,500 feet) below the surface. No evidence is recorded of extreme erosion at the site. Extrapolation from a relatively high river-incision rate in Holocene time shows erosion to a depth of 63 meters (210 feet) in the next 10,000 years. Projections of average Quaternary conditions indicate that erosion of 100 meters (330 feet) would occur over the next 1 million years. Projections of Quaternary erosional conditions indicate that the waste would remain isolated after 10,000 years. Considering the planned depth of the repository, it is unlikely that erosion will lead to releases of radionuclides to the accessible environment in the next 10,000 years.

At the Hanford site, the depth to the Cohassett flow top is 869 to 943 meters (2,850 to 3,093 feet). The site does not show evidence of extreme erosion during the Quaternary Period. Because the depth of erosion is geomorphically controlled by base level, future incision is limited to depths above the minimum sea level. Past glacially induced sea-level changes indicate that erosion at the site could proceed no further than about 440 meters (1,443 feet) above the top of the candidate horizon. The depth of the candidate horizon and the geologic setting of the site are such that the waste would not be expected to be uncovered during the first million years after repository closure. There is little chance, if any, of erosion leading to a release of radionuclides to the accessible environment over the next 10,000 years.

At the Richton site, the waste would be emplaced at a depth of 646 meters (2,119 feet). No evidence of sustained extreme erosion during the Quaternary Period is found in the geologic setting of the site. The geomorphic processes that have been in operation during the Quaternary Period have resulted in a long-term erosion rate of 1.2 meters (4 feet) per 10,000 years. This rate would result in the removal of 120 meters (394 feet) of material in 1 million years, leaving 526 meters (1.718 feet) of material over the repository. The chance of erosion removing the entire thickness of overdome sediments is much less than 1 in 1 million. Thus, it is very unlikely that erosion over the next 10,000 years would lead to any radionuclide releases to the accessible environment.

At Yucca Mountain, the minimum thickness of the overburden above the repository would be about 230 meters (750 feet). For about 50 percent of Yucca Mountain, the overburden is more than 300 meters (984 feet). Average stream-incision rates during the past 300,000 years have not been extreme, and there has been little change in the patterns of erosion at the site during the Quaternary Period. On the basis of average stream-incision rates, the shallowest portion of the repository is expected to remain buried much longer than 1 million years. Over a period of 10,000 years, erosional processes would be expected to remove only 1 meter (3 feet) of overburden. The probability that erosion would induce a loss of isolation is less than 1 in 1 million over the next 10,000 years. Thus, although the Yucca Mountain site does not meet the favorable condition on the depth of emplacement, it appears that the probabilities of erosion causing a loss of isolation are lower than those considered credible in EPA regulations (40 CFR Part 191).

Summary of the comparative evaluation

At all the sites, the underground repository can be placed deep enough to protect it from erosional processes acting on the surface. The predicted rates of erosion are low at all five sites. All waste-emplacement horizons are too deep for credible geomorphic processes to adversely affect the performance of the repository. Although the rates of erosion vary from site to site, the variation is not significant. None of the sites is expected to erode to such an extent that the waste would be uncovered during the first 1 million years. It is also very unlikely that erosion at any of the sites would result in releases of radionuclides during the first 10,000 years. Therefore, all sites are approximately equivalent with respect to the erosion guideline.

7.2.1.6 Dissolution

The qualifying condition for postclosure dissolution is as follows:

> The site shall be located such that any subsurface rock dissolution will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in §960.4-1. In predicting the likelihood of dissolution within the geologic setting at a site, the DOE will consider the evidence of dissolution

within that setting during the Quaternary Period, including the locations and characteristics of dissolution fronts or other dissolution features, if identified.

Major consideration

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-6), one major consideration is identified that influences the favorability of the sites with respect to the qualifying condition: evidence of host-rock dissolution during the Quaternary Period. This major consideration is influenced by several contributing factors, such as the solubility of the host rock under nonextreme geologic and hydrologic conditions, unusual ground-water chemistry, and evidence of significant dissolution during the Quaternary Period. The consideration is directly related to the qualifying condition through concern about the disruption of the natural and engineered barriers by the dissolution of the host rock. Such disruption would result in the potential for exceeding the radionuclide-release limits set by the NRC and the EPA. A summary of the evaluation for each site follows.

Evaluation of sites in terms of the major consideration

The Davis Canyon site is 16 kilometers (10 miles) from the nearest known or potential dissolution feature. Although data on the rate of migration of dissolution fronts in the Paradox Basin are not available, the rates estimated for other basins suggest that a dissolution front would not reach the site for at least 10,000 years. However, it should be noted that the use of such an extrapolation technique increases the level of uncertainty in this estimate. Other known and suspected dissolution features in the area include the Lockhart Basin, 19 kilometers (12 miles) to the north; Beef Basin, 22 kilometers (14 miles) to the southwest; the Needles Fault Zone, 18 kilometers (11 miles) to the west; and the Shay/Bridger Jack/Salt Creek graben system, 16 kilometers (10 miles) to the south. Data derived from field mapping and geophysical logging near the site have not revealed features that would indicate Quaternary dissolution. However, the saline ground waters of the overlying Honaker Trail Formation and the underlying Leadville Formation are thought to indicate past or continuing dissolution of the salt in the Paradox Formation.

The Deaf Smith site is somewhat further from active dissolution fronts than Davis Canyon. Dissolution at or above the repository level is known to occur 103 kilometers (64 miles) to the west, 29.8 kilometers (18.5 miles) to the north and 118 kilometers (73 miles) to the east of the Deaf Smith site. The rates of migration for these dissolution fronts have been calculated from data on the level of salinity in streams. These data suggest that the most rapid rate of migration for the dissolution fronts is 0.98 meter (3.2 feet) per year for the eastern front, while the northern front is migrating at a rate of 0.0008 meter (0.0024 foot) per year. The rate of dissolution for the western front is expected to be even lower. These calculations are based on the assumption that the dissolution front is uniform, which could underestimate the actual rate of dissolution. Within the basin, interior dissolution is evident in the uppermost salt sequence beneath the High Plains aquifer, as indicated by data from dissolution wells. However, the rate of

Table 7-6. Guideline-condition findings by major consideration--dissolution[a,b]

Condition[c]	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
Favorable condition					
No evidence that the host rock within the site was subject to significant dissolution during the Quaternary Period.	P	P	P	P	P
Potentially adverse condition					
Evidence of dissolution within the geologic setting--such as breccia pipes, dissolution cavities, significant volumetric reduction of the host rock or surrounding strata, or any structural collapse--such that a hydraulic interconnection leading to a loss of waste isolation could occur.	P	P	NP	P	NP

[a] Key: NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

[c] All of the conditions in this table are associated with one major consideration: effects of dissolution processes on waste isolation.

dissolution is very slow and has been estimated to be 0.000064 meter (0.000021 foot) per year. No dissolution fronts near the Deaf Smith site or in the interior basin are expected to intersect the repository horizon in less than 100,000 years.

The rock at the Hanford site consists of minerals that are not readily soluble, and significant dissolution leading to radionuclide releases from the site is not considered credible. It is highly unlikely that dissolution will occur along fractures within the repository during or after the thermal phase to the extent that the permeability of the fracture system will increase. The permeability of the fracture system will probably decrease because of the alteration of glass and the formation of clays and zeolites within the fractures.

The Richton site has no topographic depressions over the salt dome, and limited data suggest that the Tertiary sediments overlying the dome are laterally continuous. There are two relatively small, closed circular depressions just off the eastern flank of the dome that appear to be the result of near-surface processes; however, at this time, their origin is uncertain. Samples of ground water from a shallow fresh-water aquifer reveal possible saline anomalies on the south side of the dome (downgradient of the dome). These anomalies were identified on the basis of a very limited number of boreholes; therefore, the origin of the high salinity level in the water of the upper aquifer is unknown at this time. Possible origins for the salinities include salt-dome dissolution, variability of aquifer conditions, and artificial contamination.

The Yucca Mountain site is composed of rock whose minerals are not readily soluble, and significant dissolution leading to radionuclide releases from the site is not considered credible. It is highly unlikely that dissolution will occur along fractures within the repository during or after the thermal phase to the extent that the permeability of the fracture system will increase.

Summary of comparative evaluation

Hanford and Yucca Mountain are the most favorable sites for the dissolution guideline because the host rocks and surrounding unit consist of minerals that are not readily soluble.

The Davis Canyon, Deaf Smith, and Richton sites are less favorable. Available data suggest that dissolution probably occurred at each salt site during the Quaternary Period, but the rates of dissolution are too low to lead to a loss of waste isolation. There is, however, considerable uncertainty associated with these rates because of the limited data base for each site.

7.2.1.7 Tectonics (postclosure)

The qualifying condition for postclosure tectonics is as follows:

> The site shall be located in a geologic setting where future tectonic processes or events will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in §960.4-1. In predicting the likelihood of potentially disruptive tectonic processes or events, the DOE will consider the structural, stratigraphic, geophysical and seismic evidence for the nature and rates of tectonic processes and events in the geologic setting during the Quaternary Period.

Major consideration

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-7), one major consideration is identified that influences the favorability of the sites with respect to the qualifying condition. This major consideration concerns estimates and projections of igneous activity and tectonic processes over the next 10,000 years and the effect of these processes on radionuclide releases. It is directly related to the qualifying condition through the evaluation of radionuclide releases attributed to potential tectonic phenomena. It is derived from the favorable condition and the six potentially adverse conditions.

The contributing factors for this major consideration include evidence of tectonic or igneous activity during the Quaternary Period, the likelihood for the next 10,000 years of tectonic and igneous events that could alter the regional ground-water-flow system, the historical record of seismicity, the correlation of earthquakes with tectonic features, evidence of Quaternary tectonic processes (especially at the repository site), and the potential effects of tectonic and igneous events on the repository. The rates of igneous and tectonic activities cannot be evaluated individually; these conditions must be evaluated together to determine their impact on the total isolation system, and therefore only one major consideration was identified for this guideline. A summary of the evaluation for each site follows.

Evaluation of sites in terms of the major considerations

In the geologic setting of the Davis Canyon site, Quaternary uplift has averaged less than 0.60 meter (2 feet) per 1,000 years. Although no surface faults have been identified at the site, Quaternary faulting may be present in the vicinity of the site at Shay Graben. These faults, however, may be related to salt dissolution rather than tectonism. These faults do not trend toward the site, nor have preliminary investigations shown any surface faults at the site. No known igneous activity has occurred within the geologic setting in the last 2 to 3 million years. No earthquakes have been observed within the site, but the historical record of seismicity is limited. The Paradox Basin has been classified as a relatively low seismic hazard region. However, there is a possibility that the south Shay Graben fault may be capable of producing an earthquake larger than any observed in the geologic setting. The geologic record does not show that any natural impoundments on

Table 7-7. Guideline-condition findings by major consideration-tectonics (postclosure)[a,b]

Condition[c]	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
Favorable condition 1					
The nature and rates of igneous activity and tectonic processes (such as uplift, subsidence, faulting, or folding), if any, operating within the geologic setting during the Quaternary Period would, if continued into the future, have less than 1 chance in 10,000 over the first 10,000 years after closure of leading to releases of radionuclides to the accessible environment.	P	P	P	P	NP
Potentially adverse condition 1					
Evidence of active folding, faulting, diapirism, uplift, subsidence, or other tectonic processes or igneous activity within the geologic setting during the Quaternary Period.	P	P	P	P	P
Potentially adverse condition 2					
Historical earthquakes within the geologic setting of such magnitude and intensity that, if they recurred, could affect waste containment or isolation.	NP	NP	NP	NP	NP
Potentially adverse condition 3					
Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or the magnitude of earthquakes within the geologic setting may increase.	P	NP	P	NP	P
Potentially adverse condition 4					
More-frequent occurrences of earthquakes or earthquakes of higher magnitude than are representative of the region in which the geologic setting is located.	NP	NP	NP	NP	NP
Potentially adverse condition 5					
Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such magnitudes that they could create large-scale surface-water impoundments that could change the regional ground-water flow system.	NP	NP	NP	NP	NP
Potentially adverse condition 6					
Potential for tectonic deformations—such as uplift, subsidence, folding, or faulting—that could adversely affect the regional ground-water flow system.	NP	NP	NP	NP	NP

[a] Key: NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

[c] All of the conditions in this table are associated with one major consideration: nature and rates of tectonic processes and igneous activity that may affect waste isolation.

the scale necessary to cause large changes in the regional ground-water-flow system occurred in the geologic setting. Regional uplift will not affect the physical integrity of the repository and will be too small to significantly modify ground-water-flow systems in the next 10,000 years. Reactivation of the basement faults beneath the site is possible, but it is doubtful that displacements large enough to propagate these features through the ductile rocks of the Paradox Formation would occur in the next 10,000 years. In general, tectonic data indicate that the likelihood of disruptive tectonic events is very low and suggest that igneous or tectonic activity at the Davis Canyon site could not lead to radionuclide releases greater than regulatory limits after repository closure.

At the Deaf Smith site, data were collected by reviewing published literature and conducting preliminary field surveys. There is no evidence of igneous activity during the Quaternary Period at the Deaf Smith site. The nearest igneous activity during the Quaternary occurred about 160 kilometers (99 miles) west of the site, outside the geologic setting. Quaternary tectonic processes were probably negligible near the site. Regional uplift or subsidence is not recognized, but the possibility that these processes occurred on a small scale during the Quaternary Period has not been ruled out. The site is located in a region of low seismicity. Quaternary faulting and folding of a tectonic (or seismogenic) nature are not recognized in the Palo Duro Basin. No large damaging earthquakes have occurred in the geologic setting during the period of the historical record. The terrain of the site and its vicinity is flat and would not be affected by natural phenomena large enough to cause large-scale surface-water impoundments. Small amounts of uplift or subsidence are not likely to adversely affect the regional ground-water flow over the next 10,000 years. Some uncertainty exists because site-specific information on subsurface faulting has yet to be fully evaluated. However, the likelihood of disruptive tectonic events affecting any releases of radionuclides after closure is thought to be extremely low.

For the Hanford site, preliminary estimates of the rates of tectonic deformation suggest low long-term average rates of strain. Volcanism in the Columbia River Basalt Group ceased approximately 6 million years ago. Although Quaternary volcanism has occurred in the western Columbia Plateau, it appears to be more closely related to volcanism in the Cascades. There are faults within the Columbia Plateau that are interpreted to have been active during the Quaternary Period. Seismic activity has been monitored at Hanford since 1969, but detailed seismic monitoring at the proposed repository depth is only beginning. Some of the faults in the geologic setting could be associated with earthquakes larger than the historical maximum. Available data do not permit the precise determination of slip and recurrence rates for specific faults; however, on the basis of current knowledge, earthquakes near the site would be relatively small, with long recurrence rates for larger events (a magnitude greater than about 5.5). Earthquakes are not currently associated with mapped geologic structures, nor do hypocenters align in a manner that suggests unmapped, buried, or steeply dipping faults occur in the Pasco Basin. It does not appear that natural phenomena or tectonic deformations would create large-scale surface-water impoundments that would cause significant changes in the regional ground-water-flow system.

Although the rate of deformation at Hanford does not appear to be significant enough to affect the release of radionuclides, there is

considerable uncertainty because microearthquake swarms have been observed in the basalt during the past 16 years, though no swarms have occurred recently in the basalt at the site. The potential effects of microearthquake swarms on system performance (including the ground-water-travel time, system geochemistry, and waste-package integrity) suggest that the likelihood of tectonic phenomena affecting the site's ability to isolate waste over the next 10,000 years is very low.

At the Richton site, the evidence from the geologic setting suggests that no igneous activity and only minor tectonic activity occurred during the Quaternary Period. The principal active tectonic process during the Quaternary Period is regional uplift. Diapirism does not appear to have occurred at the Richton Dome. There has been no igneous activity in or near the Mississippi salt basin since the Cretaceous Period (about 60 million years ago). There is no evidence of Quaternary seismogenic fault movement in the geologic setting, and the infrequent seismic activity that does occur is low in magnitude. The nearest known earthquake epicenter is 75 kilometers (45 miles) away. The region has no large surface-water impoundments from tectonic or igneous processes. Projections of uplift based on Quaternary data suggest that its rates are too low (0.01 meter per 1,000 years) to adversely affect the regional ground-water-flow system during the next 10,000 years. On the basis of the Quaternary record, future tectonic processes and events are not likely to be disruptive, and the likelihood of disruptive tectonic events is very low.

Much of the background data for the evaluation of tectonic activity at Yucca Mountain has been developed through many years of study related to nuclear weapons testing at the Nevada Test Site. The assessment of future tectonic processes is uncertain and difficult for Yucca Mountain. There is evidence that volcanism and faulting occurred in the vicinity of the site during the Quaternary Period. In addition, the seismicity of the region is not understood well enough to rule out the possibility of large earthquakes (magnitude of 7 or greater) occurring in the region after closure. According to previously published estimates of recurrence intervals, regional return periods for earthquakes with a magnitude of 7 or greater are probably on the order of 25,000 years. At present, a preliminary conclusion could be made that the north-trending faults at the site should be considered potentially active, even though the absence of fault scarps and the low level of seismic activity suggests they are not active. The geologic setting of Yucca Mountain is not yet well enough understood to preclude the possibility of future earthquakes larger than those that have occurred at or near the site.

The formation of large-scale surface-water impoundments by natural phenomena like landslides, subsidence, or volcanic activity is not likely in the area of Yucca Mountain. There is also a very small potential for tectonic deformation at the site of a magnitude that would affect the regional ground-water flow. On the basis of available information, it appears unlikely that volcanic events or future tectonic processes and events would adversely affect the containment and isolation capabilities of the repository, although numerical probabilities have not been determined for most processes. This conclusion is based on the moderate (although uncertain) probabilities of tectonic events, the likelihood that the ground-water travel time is long and the flux is low, the selection of waste-emplacement areas away from

recognizable fault zones, the structural integrity of the waste package, and the geochemical characteristics of the site.

Summary of comparative evaluation

The most favorable sites with respect to the postclosure tectonics guideline are Davis Canyon, Deaf Smith, and Richton. Although the Davis Canyon site appears to have a higher rate of tectonic activity near the site (as indicated by potential Quaternary faulting), there is a very low likelihood that tectonic events could lead to releases at any of these sites, and none show evidence of igneous activity in the geologic setting. Active faulting may also be present in the geologic setting of Davis Canyon, but no surface faults have been identified at the site, and seismic and geologic evidence qualitatively suggests that the region will be stable over the long term. The available data suggest that there is very little likelihood of disruptive tectonic or igneous events during the next 10,000 years at all three sites. Both the Deaf Smith and the Richton sites have experienced no igneous activity and insignificant tectonic activity during the Quaternary Period. There are no known Quaternary seismogenic faults in either geologic setting, and the level of seismicity at both sites appears to be very low.

Hanford is slightly less favorable than the salt sites for this guideline. There is some evidence that deformation is occurring within the basalts at Hanford, but the pattern of deformation qualitatively matches the pattern of known seismicity, suggesting that earthquakes and rupture planes would be relatively small and recurrence times generally long. There is some uncertainty because microearthquake swarms in the basalts have been observed during the past 16 years. In addition, no microearthquakes (nonswarm) have been observed within the repository site at the depth of the basalts. The likelihood of tectonic phenomena affecting the ability of the site to isolate waste over the next 10,000 years is very low.

Yucca Mountain is less favorable than the other sites. Quaternary faults are present within 1 to 6 kilometers of the site. Their effects on the potential for ground motion and on ground-water flow need to be assessed. The likelihood of volcanism may be high enough for volcanism to be considered in performance assessment. However, the effects of igneous and tectonic activity on system performance (qualifying condition) at Yucca Mountain are not expected to lead to radionuclide releases greater than those allowed by regulation. This assessment accounts for ground-water flux and travel time, waste emplacement away from recognized fault zones, the structural integrity of the waste package, and the geochemical characteristics of the site.

7.2.1.8 Human interference

The potential for human interference after the closure of the repository requires an analysis of (1) the natural resources at or near a site, addressing historical, current, and future exploration for, and uses of, these resources, and (2) site ownership and control. Evaluations of these two separate technical guidelines are provided below.

7.2.1.8.1 Natural resources

The qualifying condition for natural resources is as follows:

> This site shall be located such that--considering permanent markers and records and reasonable projections of value, scarcity, and technology--the natural resources, including ground water suitable for crop irrigation or human consumption without treatment, present at or near the site will not be likely to give rise to interference activities that would lead to radionuclide releases greater than those allowable under the requirements specified in §960.4-1.

or considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-8), three major considerations are identified that influence the favorability of the sites. In decreasing order of importance, they are (1) evidence of subsurface mining, resource extraction, and drilling sufficient to affect containment and isolation; (2) potential for foreseeable human activities that could affect containment and isolation; and (3) potential for postclosure intrusion for resource extraction. Although the major considerations are listed in decreasing order of importance, the differences in their importance are small, particularly between the second and the third considerations.

Evaluation of the sites in terms of the major considerations

Evidence of subsurface mining, resource extraction, and drilling sufficient to affect containment and isolation. This consideration assesses the potential effects on waste containment and isolation of existing mines and drillholes within the site. Contributing factors include the presence of active and closed mines as well as evidence of deep drilling and related resource extraction. This consideration is derived from the second and the third potentially adverse condition and is the most important major consideration because existing mines or drill holes could act as pathways for radionuclide migration to the accessible environment. A summary of the evaluation for each site follows.

At the Davis Canyon site, existing uranium mines extend to a maximum depth of 11 meters (35 feet) and are restricted to the Chinle Formation, which has been eroded from most of the repository operations area. These existing excavations are not thought to be extensive enough or deep enough to affect the repository. No drilling is known to have occurred within the site. The nearest hydrocarbon-exploration borehole of appreciable depth is 8 kilometers (5 miles) from the boundary of the repository operations area.

There is no subsurface mining at the Deaf Smith site. There are no known wells that penetrate below the Ogallala aquifer and no known hydrocarbon-exploration holes at the site. Deep drilling at the site is unlikely to have occurred in the past.

Table 7-8. Guideline-condition findings by major consideration--natural resources[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: EVIDENCE OF SUBSURFACE MINING, RESOURCE EXTRACTION, AND DRILLING SUFFICIENT TO AFFECT CONTAINMENT AND ISOLATION					
Potentially adverse condition 2					
Evidence of subsurface mining or extraction for resources within the site if it could affect waste containment or isolation.	NP	NP	NP	NP	NP
Potentially adverse condition 3					
Evidence of drilling within the site for any purpose other than repository-site evaluation to a depth sufficient to affect waste containment and isolation.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 2: POTENTIAL FOR FORESEEABLE HUMAN ACTIVITIES SUFFICIENT TO AFFECT CONTAINMENT AND ISOLATION					
Potentially adverse condition 5					
Potential for foreseeable human activities such as ground-water withdrawal, extensive irrigation, sub-surface injection of fluids, underground pumped storage, military activities, or the construction of large-scale surface-water impoundments--that could adversely change portions of the ground-water flow system important to waste isolation.	NP	NP	P	NP	NP
MAJOR CONSIDERATION 3: POTENTIAL FOR POSTCLOSURE INTRUSION TO EXTRACT RESOURCES					
Favorable condition 1					
No known natural resources that have or are projected to have in the foreseeable future a value great enough to be considered a commercially extractable resource.	NP	NP	NP	NP	P
Favorable condition 2					
Ground water with 10,000 parts per million or more of total dissolved solids along any path of likely radionuclide travel from the host rock to the accessible environment.	P	P	NP	P	NP

Table 7-8. Guideline-condition findings by major consideration--natural resources[a,b] (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 3: POTENTIAL FOR POSTCLOSURE INTRUSION TO EXTRACT RESOURCES (Continued)					
Potentially adverse condition 1					
Indications that the site contains naturally occurring materials, whether or not actually identified in such form that (i) economic extraction is potentially feasible during the foreseeable future or (ii) such materials have a greater gross value, net value, or commercial potential than the average for other areas of similar size that are representative of, and located in, the geologic setting.	P	P	P	P	NP
Potentially adverse condition 4					
Evidence of a significant concentration of any naturally occurring material that is not widely available from other sources.	NP	NP	NP	NP	NP

[a] Key: NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

Current and past mining or extraction activities in the area of the Hanford site include some quarrying for sand and gravel as well as a small natural gas field that ended production in 1941. The quarries are excavated pits that are generally less than 18 meters (60 feet) deep. The gas field was located approximately 11 kilometers south of the site. No other current or past production of hydrocarbons has been reported within 100 kilometers of the larger Hanford Site. Recent hydrocarbon exploration in the Columbia Plateau has been focused on the sedimentary sequence beneath the basalt; wells drilled to date have been noncommercial, but some natural gas has been recovered. Although methane has been found as dissolved gas in ground water from the Grande Ronde Formation beneath the site, the hydrocarbon potential for this area is speculative at best. Boreholes drilled near the site for purposes other than repository-site evaluation are significantly shallower than the candidate repository horizon and would not affect waste containment or isolation.

At the Richton site, there is no evidence of boreholes, shafts, or other excavations that penetrate the repository horizon within the salt dome. Eight mineral-exploration boreholes have been drilled into salt with a maximum reported penetration of 6.4 meters (21 feet). Within 10 kilometers (6.2 miles) of the dome, 34 sulfur-exploration wells and 32 petroleum-exploration wells have been drilled. The water wells within the area are shallow (less than 366 meters (1,200 feet)) and are drilled into the upper aquifer. The closest fluid-injection wells are at least 4.8 kilometers (3 miles) from the flank of the dome. Waste containment and isolation are not expected to be significantly affected by the presence of shallow boreholes or the potential for increased dissolution associated with the petroleum-exploration wells on the sloping flank of the dome.

There has been no subsurface mining or extraction of resources at Yucca Mountain. There is little likelihood that unknown excavations exist at the site other than shallow prospecting pits. Before the repository investigations began, one borehole had been drilled 7 kilometers (4 miles) southeast of the site (water well J-13), and another had been drilled approximately 15 kilometers (9 miles) to the northeast (water well J-12). There has been no drilling at Yucca Mountain for purposes other than repository-site evaluation.

Potential for foreseeable human activities that could affect containment and isolation. Factors contributing to this consideration include the potential for ground-water withdrawal, irrigation, the injection of fluids, underground pumped storage, and large-scale surface-water impoundments. Changes to the site's ground-water system can directly affect the releases of radionuclides to the accessible environment. This consideration is derived from the fifth potentially adverse condition and is the second most important major consideration. Changes to the site's ground-water system can directly affect the releases of radionuclides to the accessible environment. This consideration is not as important as the first major consideration because it is based on projected, more speculative human activities that may affect isolation, whereas the first consideration is based on existing evidence of resources that could affect isolation.

In assessing the likelihood of postclosure intrusion, the DOE will consider the estimated effectiveness of the permanent markers and records required by NRC regulations in 10 CFR Part 60. Human-intrusion events are considered to be credible only if it is assumed that the monuments provided for in the NRC regulations are permanent enough to serve their intended purpose. Thus, in evaluating this major consideration, the environmental assessments have qualitatively considered the effectiveness of markers and records in reducing the likelihood of human intrusion in the controlled area. A summary of the evaluation for each site follows.

Because of limited potable water and resources within and near the Davis Canyon site, the potential for foreseeable human activities to adversely affect the ground-water-flow system is expected to be very low.

At the Deaf Smith site, good-quality ground water that is suitable for irrigation and domestic use is drawn entirely from the Ogallala aquifer. The ongoing depletion of the Ogallala aquifer will not reverse the downward flow potential at the site. The potential for the subsurface injection of fluids is considered to be low because of the low potential for petroleum development in the future.

At the Hanford site, there is a potential for ground-water withdrawal for irrigation. Insufficient data are available to determine whether such human activities could adversely change portions of the ground-water flow system that are important to waste isolation. However, it is believed that, even if portions of the ground-waste-floor system were to change, there would be no significant effect on waste isolation itself.

At the Richton site, the potential to adversely affect the ground-water-flow system is expected to be very low. Potential human activities are very unlikely to affect ground-water travel through the salt stock; this includes activities that may change fresh-water aquifers. The likelihood of pumped storage in the controlled area is also expected to be very low, considering the permanent markers and records.

Although potable ground water is present at the Yucca Mountain site, future generations are not likely to drill for water from the top of Yucca Mountain, because it would be easier to drill for water in the surrounding areas. Because isolation depends primarily on the thick unsaturated zone, withdrawal of water outside the controlled area would not adversely affect the ground-water system important to isolation.

Potential for postclosure intrusion to extract resources. This consideration includes estimates of, and the potential for, postclosure intrusion for resource extraction. Contributing factors include the presence or indication of resources (including water) at the site, their value, scarcity, and depth, as well as their availability from other sources. This condition is derived from the first and the second favorable conditions and the first and the fourth potentially adverse conditions. This consideration is third in importance because the potential for resources is based on speculative or indirect evidence. Nevertheless, this consideration is significant because exploration for, or the extraction of, resources can create pathways for radionuclides to reach the accessible environment. A summary of the evaluation for each site follows.

Uranium and vanadium deposits are present in the vicinity of the Davis Canyon site, and some production has occurred at the site itself; however, the uranium resources at the site are believed to be less significant than those in other parts of southeastern Utah. In addition, commercial-grade underground potash deposits are present in the vicinity of the site, but they may not be economic because they are located at excessive depths and are less extensive than deposits in other parts of Utah. Small amounts of sand, gravel, and potable water have been extracted in the vicinity of the site. None of these resources has greater potential within the area of the site than outside it. Potential hydrocarbon resources are believed to be significantly smaller within the site than in similar areas outside the site. The ground-water is of poor quality, with the total dissolved solids exceeding 10,000 parts per million.

At the Deaf Smith site, ground water is being extracted from the Ogallala aquifer. The use of this water resource does not pose a threat to the long-term integrity of the repository. Ground water along the likely pathways of radionuclide travel is not suitable for human consumption because it contains dissolved solids at concentration exceeding 10,000 parts per million. The hydrocarbon potential at the site is not considered to be significant, but exploration for oil and gas in the future cannot be discounted. No other mineral resources, such as uranium and construction aggregates, are present in unique quantities at the site. The bedded salt may be considered a halite resource. There are no known concentrations of naturally occurring materials that are not widely available from other sources.

At the Hanford site, there are no known metallic or petroliferous resources that have or are projected to have a value great enough to be commercially extractable. However, there are indications that the site contains ground-water resources and natural gas that may be economically feasible to extract in the foreseeable future. Although hydrocarbon source beds may exist beneath the basalt, there is no evidence to date of significant concentrations of any naturally occurring resources that are unique to the site.

The Richton Dome is the largest of 35 shallow salt domes in the Mississippi salt basin. Because of its size and depth, it is an excellent candidate for underground storage. The purity of the salt (91 percent sodium chloride) also indicates that the dome may be a candidate for salt extraction by solution mining or conventional mining methods. In comparison with other shallow salt domes, the potential for storage or salt extraction at the Richton Dome is above average because of its large size, even though salt is widely available from other sources and the dome's potential use as an underground storage facility is not unique. Commercial hydrocarbon resources are not known to exist at the Richton Dome.

Yucca Mountain has no energy or mineral resources for which extraction is feasible in the foreseeable future. No known resources are present at Yucca Mountain that have greater commercial potential than those in other areas in its geologic setting, nor is there evidence of any significant concentration of potentially valuable resources at Yucca Mountain. The mineral-resource potential of the Yucca Mountain site is considered low. The ground water along likely flow paths of radionuclide travel has less than 10,000 parts per million of total dissolved solids.

Summary of comparative evaluation

On the basis of the three major considerations, Yucca Mountain is the most favorable site; Davis Canyon, Deaf Smith, and Hanford are comparable; and Richton is the least favored site. The differences among the sites, however, are small. This judgment is based on the fact that there is no evidence at any of the sites of subsurface mining, extraction, or drilling sufficient to affect containment or isolation. There is also no evidence at any of the sites of a significant or unique concentration of any naturally occurring mineral or energy resources. It is expected that the use of permanent markers and records will reduce to very low values the likelihood of human intrusion within the controlled area at each of the sites.

The likelihood of any resource occurring at the Yucca Mountain site appears to be very low. The potential use of the deep aquifer outside the controlled area will not affect containment and isolation.

The Davis Canyon, the Deaf Smith, and the Hanford sites are approximately equal in favorability on the basis of the speculative potential for resources. There is a very small potential for the use of the shallow aquifer outside the controlled area at the Hanford site to affect the ground-water-flow system important to isolation.

Richton Dome is the least favorable site because of the speculative potential for resources, the possibility of undetected boreholes, and the potential for using the dome for underground pumped storage.

7.2.1.8.2 Site ownership and control

The purpose of the postclosure guideline on site ownership and control is to help ensure that the repository can function far into the future without adverse human interference. This guideline specifies that the DOE, in accordance with the requirements of the 10 CFR Part 60, is to obtain ownership of, and surface and subsurface rights to, land and minerals within the controlled area of the repository. A similar guideline on site ownership is provided for the preclosure period. The purpose of the preclosure guideline is to ensure that surface and subsurface activities during repository operation will not be likely to lead to radionuclide releases greater than those allowed by applicable regulations.

The DOE has determined that the necessary land area and controls are the same for both the postclosure and the preclosure periods at the five nominated sites. Whichever site is selected, the DOE must obtain ownership as well as surface and subsurface rights before commencing preclosure activities; there is no basis for distinguishing among the sites on their site ownership and control status at the beginning of the postclosure period. Therefore, all sites are considered to be equally favorable for this guideline.

7.2.2 POSTCLOSURE SYSTEM GUIDELINE

The results of preliminary system-performance assessments are described in Section 6.4.2 of each environmental assessment and briefly reviewed here. These preliminary assessments are based on limited geologic, hydrologic, and geochemical information, preliminary conceptual models, and relatively simple analytical techniques. The DOE is therefore not yet prepared to provide assurance that regulatory criteria will be met at any of the sites. These preliminary assessments do, however, appear adequate for evaluating the sites against the postclosure system guideline. However, the different approaches to the evaluation of performance, the preliminary nature of these assessments, and the uncertainties in the parameters on which the analyses are based all limit the ability to compare the sites in the manner required by the implementation guidelines for site comparisons that will support the recommendation of a site for development as a repository. To provide a comparative context for understanding the postclosure system guideline evaluation in Chapter 6, a brief discussion of the evaluation of each of the sites with respect to each of the capabilities addressed by the guideline is presented below.

The guideline addresses the following capabilities of the geologic setting at a site:

1. The capability of the geologic setting at the site to allow for the physical separation of the waste from the accessible environment after closure in accordance with the requirements of the EPA standard in 40 CFR Part 191, Subpart B, as implemented by 10 CFR Part 60.

2. The capability of the geologic setting at the site to allow for the use of engineered barriers to ensure compliance with the requirements of the EPA and the NRC. Two requirements are pertinent here: (1) the time of substantially complete containment (i.e., a period between 300 and 1,000 years); and (2) the limit on the rate of radionuclide releases from the engineered-barrier system (i.e., one part in 100,000 per year of the individual radionuclide inventory or one part in 100,000 per year of the total inventory calculated to be present at 1,000 years after repository closure, whichever is greater).

Capability for waste isolation. The results of the preliminary assessments indicate that the EPA standards would be met at all of the sites. For example, the mean time of ground-water travel from the repository to the accessible environment is expected to be much longer than 10,000 years at each site. On this basis alone, there is little likelihood of any release for 10,000 years or, more specifically, of exceeding the EPA standard for cumulative releases during this period. In fact, the results of the calculations for the preliminary assessments indicate that releases are likely to be negligible for much more than 10,000 years at each site. Similarly, calculations of ground-water quality indicate that the EPA's ground-water protection and individual-protection requirements will be met at each of the sites. For the Hanford site, the calculations show to a high level of confidence that less than 50 curies of iodine-129 and carbon-14--and no other radionuclides--would be released to the accessible environment in 100,000 years. The calculations for Yucca Mountain indicate that less than 100 curies

of technetium-99 and negligible quantities of any other radionuclide could be released in 100,000 years. The analyses for the salt sites show no release in 100,000 years under expected repository conditions.

Because of the different characteristics of each of the sites, different approaches to the performance analyses and varying levels of conservatism have been used for each site. For example, the constraint on release due to the slow degradation of the waste form was not taken into account in the analysis of the Hanford site. The analysis of the Yucca Mountain site does not consider the spatial distribution of waste packages throughout the repository, but assumes that the release occurs from a single location in the host rock. Transport and retardation in the saturated zone are not considered in these analyses as well. The margin of conservatism resulting from such assumptions in each case is not known at present. However, it is believed to be sufficient to compensate for the uncertainties in the site data. The preliminary performance assessments do not provide evidence to support a finding that any of the sites would not adequately isolate the waste from the accessible environment.

Requirements for engineered-barrier performance. Preliminary assessments of the engineered-barrier system indicate that this system would meet the regulatory performance objectives at all sites. For example, the analyses of waste-package performance indicate that the container lifetime is expected to exceed the 300- to 1,000-year requirement for substantially complete containment at each site. The expected container lifetime for the Hanford site exceeds 6,000 years. The analysis of the container under the conditions of the Yucca Mountain site gives a lower-bound estimate of 3,000 years and an expected lifetime of 30,000 years. At the salt sites, the lifetime of the container is calculated to be even longer, because it is expected that sufficient water will not be available to cause corrosion failure of the waste package.

For each site, the calculations of the rate of radionuclide release after the failure of the waste package suggest that the criterion for the rate of release from the engineered-barrier system would not be exceeded. At the Hanford site, the release rate for most radionuclides would be well below the regulatory criterion because of the diffusion-limited transport and the limited solubility of these radionuclides in the ground water at the site. For the few radionuclides that are highly soluble, the calculated release rates are less than 4 percent of the release-rate limit.

Without taking into account the solubility of the radionuclides themselves, the fractional release rate calculated for the Yucca Mountain site is 2.5×0^{-9} per year, well below the limit of 1×10^{-5} per year, because of the low rate expected for waste-form dissolution. At the salt sites, since it is expected that the waste packages will last indefinitely, the rate of radionuclide release from the engineered-barrier system is expected to be zero.

Extremely conservative assumptions were used in making these estimates. For example, in all cases the calculations are for releases from the waste package, which is expected to provide an upper bound to the release from the total engineered-barrier system. In addition, any containment offered by the

spent-fuel cladding was not taken into account in any of the analyses. In the analysis of the salt sites and of the Hanford site, the slow dissolution of the waste form, which can limit the rate of radionuclide release, was not taken into account. In the analyses of the salt sites and of the Yucca Mountain site, it was assumed that all packages fail simultaneously. Again, the degree of conservatism provided by these assumptions is not known at present. However, the analyses appear to be sufficient to indicate that there is no evidence that the performance criteria for the waste package and other engineered barriers would not be met at each of the nominated sites. Furthermore, the available data and the preliminary analyses based on these data have not identified any conditions or features at any of the sites that would prevent these engineered components from meeting the performance requirements.

The different approaches to the evaluation of performance, the preliminary nature of these assessments, and the uncertainties in the parameters on which the analyses are based all limit the ability to compare the sites in terms of these results. In each case the analyses are very simple. The interactions of the various factors that determine subsystem and system performance are not yet known. Finally, the analyses that can be conducted at present are too simple to address the full range of uncertainties that should be addressed in order to provide an adequate comparison of the sites. Therefore, because of the preliminary nature of these performance assessments, it does not appear that a comparison between and among the sites on the basis of the postclosure system guideline is practicable at present.

7.3 COMPARISON OF SITES ON THE BASIS OF PRECLOSURE GUIDELINES

The preclosure guidelines address (1) preclosure radiological safety; (2) the environmental, socioeconomic, and transportation-related impacts associated with repository siting, construction, operation, and closure; and (3) the ease and cost of repository siting, construction, operation, and closure. Both technical and system guidelines are provided for each of these three categories.

7.3.1 PRECLOSURE RADIOLOGICAL SAFETY

7.3.1.1 Technical guidelines

There are four technical guidelines on preclosure radiological safety: (1) population density and distribution, (2) site ownership and control, (3) meteorology, and (4) offsite installations and operations. The objective of these guidelines is to protect the health and safety of the public and the workers at the repository by keeping exposures to radiation within the limits prescribed by regulations. This section presents a comparative evaluation of the five nominated sites against these guidelines.

7.3.1.1.1 Population density and distribution

The qualifying condition for population density and distribution is as follows:

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

Major considerations

On the basis of the qualifying, favorable, potentially adverse and disqualifying conditions for this guideline (Table 7-9), two major considerations are identified that influence the favorability of the sites with respect to population density and distribution. These major considerations are (1) remoteness of the site from highly populated areas and (2) the population density at the site, near the site, and in the general region of the site. These major considerations are of equal importance and are in turn influenced by several more-specific contributing factors, which are discussed below.

Evaluation of the sites in terms of the major considerations

Remoteness. The remoteness of a site is measured by its distance from highly populated areas of 2,500 people or more, or from an area with 1,000 or more persons within 1 square mile. This major consideration is derived from the second favorable condition and the second potentially adverse condition (see Table 7-9). It relates to the qualifying condition in that the potential for radiation exposure increases with proximity to population concentrations. The second favorable condition refers to the remoteness of the site from highly populated areas, and the second potentially adverse condition addresses the proximity of the site to populated areas and areas with at least 1,000 individuals in an area that is 1 mile by 1 mile. The two contributing factors related to this major consideration are (1) the air distance of the site from population concentrations and (2) the size of those concentrations. Specifically, the closer a site is to highly populated areas, and the larger such population concentrations are, the less favorable is the site. A summary of the evaluation for each site follows.

The immediate vicinity of the Davis Canyon site contains no highly populated areas. Moab, with a population of 5,333, is the closest and is approximately 33 miles from the boundary of the controlled area. Moab is also the nearest 1-square mile area with a population of at least 1,000 persons.

The Deaf Smith County site is approximately 17 miles north of Hereford, with a population of 15,853. Hereford is also the nearest area with at least 1,000 persons in a 1-square-mile area.

Table 7-9. Guideline-condition findings by major consideration-population density and distribution[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: REMOTENESS FROM HIGHLY POPULATED AREA					
Favorable condition 2					
Remoteness of the site from highly populated areas.	P	P	P	P	P
Potentially adverse condition 2					
Proximity of the site to highly populated areas, or to areas having at least 1,000 individuals in an area 1 mile by 1 mile as defined by the most recent decennial count of the U.S. census.	NP	NP	NP	P	NP
MAJOR CONSIDERATION 2: POPULATION DENSITY					
Favorable condition 1					
A low population density in the general region of the site.	P	P	P	P	P
Potentially adverse condition 1					
High residential, seasonal, or daytime population density within the projected site boundaries.	NP	NP	NP	NP	NP

[a] Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

At the Hanford site, Sunnyside is the nearest highly populated area. It has a population of 9,229 and is approximately 15 miles southwest of the site. Sunnyside is also the closest 1-square-mile area with a population of at least 1,000.

At the Richton site, the town of Richton, with a population of 1,205 within a 1 square mile, is adjacent to the proposed boundary of the controlled area. However, the town is 2 miles from the proposed boundary of the surface facilities of the repository. The nearest highly populated area is Petal/Hattiesburg with a population of 49,300; it is 25 kilometers from the boundary of the site.

The Yucca Mountain site is remote from highly populated areas or 1-square-mile areas with a population of at least 1,000. Las Vegas Valley, the nearest highly populated area, is at a distance of approximately 85 miles.

Population density. Population density is evaluated for each site on the basis of density within the projected site boundaries, near the site, and in the general region of the site. For this analysis, "near the site" is defined as being within 10 miles of the site and "in the general region" as being within 50 miles. This major consideration is derived from the first favorable condition and the first potentially adverse condition (see Table 7-9). It relates to the qualifying condition in that a larger number of people are potentially exposed to radioactive releases as the population density in the region of a site increases. The first favorable condition is a low population density in the general region of the site, and the first potentially adverse condition addresses high residential, seasonal, or daytime population density within the projected site boundaries.

In the evaluation of this major consideration, a "low population density" is defined as being less than the average population density of the contiguous United States in 1980, or 76 persons per square mile. This major consideration is also closely related to the third disqualifying condition for this guideline, which is related to emergency planning. Specifically, as population density near the site increases, a more extensive emergency-preparedness plan is required, since protective measures would have to be taken on behalf of a larger number of people in the event of an accident. As the density on the site, near the site, and within the general region of the site increases, the favorability of the site decreases. A summary of the site evaluation for this consideration follows. The site-specific information used in the evaluation is summarized from Section 6.2.1.2 of the environmental assessments for the five nominated sites.

There is no residential or seasonal population within the projected boundaries of the Davis Canyon site. The daytime population is limited to an estimated peak of seven offroad-vehicle users. The onsite population density is therefore far below the national average. About 282 people are estimated to live within 10 miles of the site. The population density in the general region is also far below the national average, at 3.8 persons per square mile.

The Deaf Smith County site is estimated to have 27 residents within its boundaries. The seasonal population density at the site is about seven persons per square mile assuming that the 10,440 migrant workers who were in

Deaf Smith County in 1975 are evenly distributed throughout the county. The combined residential, seasonal, and daytime population density within the site boundary is approximately 10 persons per square mile. The population within 10 miles of the site is estimated to be 1,739. The population density in the general region of the site is 24 persons per square mile.

Although there are no residences or seasonal population at the Hanford site, approximately 700 persons work within the site boundary at any given time, which is equivalent to a population density of 39 persons per square mile. In addition, 4,800 persons are employed in nuclear energy jobs in the vicinity of the site. (However, because these workers receive training in safety and evacuation procedures, they are better prepared than the general public to respond to radiological hazards.) There are approximately 110 people within 10 miles of the site. The population density in the general region of the site is 43 persons per square mile. Federal ownership of the Hanford site reduces the uncertainty associated with future population growth in the area.

The residential population within the proposed controlled area of the Richton site is about 140 people, assuming that there are 50 households with an average size of 2.8 persons. However, there are no residences within the proposed restricted area. Seasonal population fluctuations are expected to be minimal. The daytime population may vary by 100 because a school is located in the southeast portion of the area of the Richton Dome. The population within 10 miles is approximately 4,610. The population density in the general region is 40 persons per square mile.

There are no residences within 6.2 miles of the Yucca Mountain site and no seasonal or daytime populations within the site boundaries. About 5,200 workers are employed at the Nevada Test Site, but most of their activities are conducted on the opposite side of the Nevada Test Site. Because of their experience with nuclear research and testing, workers at the Nevada Test Site are better prepared than members of the general public to deal with radiological hazards. The population density in the general region of the site is approximately 2.5 people per square mile. Federal ownership of the site and the surrounding area reduces the uncertainty of population growth near the site.

Summary of the comparative evaluation

Yucca Mountain is the most favorable site for both major considerations. There are no highly populated areas within 50 miles of the site, and the regional population density is the lowest of all the sites. In addition, there is no residential or seasonal population on or near the site. Davis Canyon is less favorable because it is 33 miles from the highly populated area of Moab, which has a population of 5,333. Nonetheless, the site is remote in comparison with the remaining sites. The population density in the region is also very low--288 people are located within 10 miles of the site. The Hanford site is 15 miles from Sunnyside, which has a population of 9,229. The population density in the region is 43 persons per square mile. These two factors reduce the favorability of the site. There are only 110 residents within 10 miles of the Hanford site, and the 4,800 nuclear energy workers in the vicinity of the site are better prepared than other members of the general

public to deal with radiological hazards. The Deaf Smith site is 17 miles from Hereford, which has a population of 15,853. The population density in the region is 24 persons per square mile, and 1,739 people live within 10 miles of the site. The Richton site is proximate to the town of Richton, and 4,610 people live within 10 miles. The population density in the region is 40 persons per square mile. Since there are 140 people and a school within the controlled area, and the highly populated area of Petal and Hattiesburg with a population of 49,300 is 16 miles away, the Richton Dome is the least favorable site for this guideline.

7.3.1.1.2 Site ownership and control

The qualifying condition for site ownership and control is as follows:

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

Major consideration

On the basis of the qualifying, favorable, and potentially adverse conditions of this guideline (Table 7-10), one major consideration is identified that influences the favorability with respect to the qualifying condition. It refers to the kinds of procedures that are available for acquiring land. The major consideration is, in turn, influenced by two contributing factors.

Evaluation of the sites in terms of to the major consideration

The single major consideration for this guideline is the complexity of procedures for acquiring the needed land. This consideration is derived from the favorable condition and the potentially adverse condition (see Table 7-10). The favorable condition addresses whether the DOE has present ownership and control of the site. The potentially adverse condition identifies three means of acquiring land: voluntary purchase-sell, condemnation, and undisputed agency-to-agency transfer. If the DOE is unable to acquire land through one of these means, Congressional action will be required. Each of these land-acquisition mechanisms involves different legal procedures.

There are two ways the DOE can acquire private or State land: voluntary purchase-sell and condemnation. Voluntary purchase-sell means that a landowner voluntarily sells his land to the DOE under the provisions of the Uniform Relocation Assistance and Real Property Acquisition Act of 1970. If a landowner is not willing to sell needed property, the DOE can acquire it by right of eminent domain, or condemnation, under the provisions of the Declaration of Taking Act (40 USC Section 258a). The DOE estimates that about 90 days would be required to condemn privately owned land.

Table 7-10. Guideline-condition findings by major consideration--site ownership and control (preclosure)[a,b]

Condition[c]	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
Favorable condition					
Present ownership and control of land and all surface and subsurface mineral and water rights by the DOE.	NP	NP	P	NP	NP
Potentially adverse condition					
Projected land-ownership conflicts that cannot be successfully resolved through voluntary purchase-sell agreements, nondisputed agency-to-agency transfers of title, or Federal condemnation proceedings.	P	NP	NP	NP	P

[a] Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

[c] Both conditions in this table are related to one major consideration: complexity of procedures for acquiring needed land.

There are two ways that the DOE can obtain jurisdiction over lands that are currently controlled by another Federal agency: agency-to-agency transfers and legislative transfer by Congress. The DOE can acquire land from another Federal agency for up to 20 years under the provisions of the Federal Land Policy and Management Act of 1976. However, to meet the requirements of applicable NRC regulations (10 CFR 60.121), the DOE must obtain permanent jurisdiction over the repository operations area and the controlled area. This permanent withdrawal will require a legislative transfer.

In evaluating the sites against this guideline, the DOE considered what property would be required for repository construction, operation, closure, and decommissioning. Land-acquisition procedures, such as leasing, that might be employed during site characterization were not considered.

Sites for which land will be easier to acquire from a procedural and legal point of view are more favorable. This does not mean that the DOE discounts the socioeconomic impact of acquiring lands, especially privately owned land. The socioeconomic impacts of land acquisition are considered under the socioeconomics guideline. The DOE recognizes, for example, that the condemnation of privately owned lands will disrupt the lives of displaced landowners. Nevertheless, condemnation is legally more straightforward than obtaining the Congressional authorization that would be needed to acquire certain lands under the control of other Federal agencies. The DOE estimates that about 90 days would be required for condemnation, whereas a Federal-land transfer requiring Congressional authorization could take longer and the result could be less certain. Thus, from a strictly procedural point of view, it is easier for the DOE to acquire permanent jurisdiction over State and private lands than Federal lands.

The complexity of procedures for acquiring land depends, in turn, on current ownership (DOE, other Federal agency, State, or private) and the number of landowners. Current ownership determines which acquisition procedures are available. Similarly, the greater the division among landowners (Federal, State, private), the more complicated the overall land-acquisition procedures. A summary of the evaluation for each site follows.

Most of the Davis Canyon site is Federal land controlled by the Bureau of Land Management (BLM), although small portions are owned by the State of Utah and private parties. A Congressional action would be required to obtain permanent jurisdiction over the BLM portion of the site. Although the DOE would prefer to acquire State and private lands by voluntary purchase-sell agreements, the land could be acquired by condemnation if necessary.

The Deaf Smith site is privately owned, and ownership is divided among at least eight parties. The Richton site is also on private lands with ownership divided among many parties. Although the DOE would prefer voluntary purchase-sell agreements with the current owners, the land can be acquired by condemnation.

The DOE controls all surface and subsurface rights to the Hanford site and the surrounding area. The DOE would not have to acquire any land for a repository at Hanford.

The Federal land of the Yucca Mountain site is under the control of three agencies: the DOE, the BLM, and the Department of Defense (the Air Force). Congressional action would be required to permit a permanent transfer of land from the BLM and the Air Force to the DOE, but the action is not expected to be disputed by these agencies.

Summary of the comparative evaluation

The Hanford site is the most favorable for the preclosure guideline on site ownership and control because the DOE has control over the entire site. The Deaf Smith and the Richton sites are on private land that can be acquired by voluntary purchase-sell agreements or the right of eminent domain. Control over the Yucca Mountain site is divided among three Federal agencies, and Congressional action would be required to permit a permanent transfer to the DOE. The Davis Canyon site is the least favorable because the ownership of land is divided among the BLM, the State of Utah, and private parties, and a combination of actions (voluntary purchase-sell agreements, condemnation, and Congressional action) would be required to acquire the needed land.

7.3.1.1.3 Meteorology

The qualifying condition for meteorology is as follows:

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

Major considerations

The qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-11) led to the identification of two major considerations that influence favorability with respect to the qualifying condition. These major considerations, in order of decreasing importance, are (1) conditions that affect the transport of radionuclide releases in the atmosphere and the significance of transport, and (2) extreme weather phenomena. The transport consideration addresses prevailing meteorological conditions, while the extreme weather consideration addresses specific episodes. These major considerations are influenced by several contributing factors which are discussed below.

Evaluation of the sites in terms of the major considerations

Conditions that affect transport and the significance of transport. This major consideration addresses meteorological conditions that affect the transport of airborne radionuclide releases to unrestricted areas where the general public might be exposed. Contributing factors are the dispersion characteristics of the atmosphere, wind speed and direction, episodes of stagnation, atmospheric mixing levels, the terrain, and the locations of nearby populations. This is the most important major consideration under this guideline because the potential for a preferential transport of radionuclides

Table 7-11. Guideline-condition findings by major consideration—meteorology[a,b]

Condition[c]	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
Favorable condition					
Prevailing meteorological conditions such that any radioactive releases to the atmosphere during repository operation and closure would be effectively dispersed, thereby reducing significantly the likelihood of unacceptable exposures to any member of the public in the vicinity of the repository.	NP	P	P	P	P
Potentially adverse condition 1					
Prevailing meteorological conditions such that radioactive emissions from repository operation and closure could be preferentially transported toward localities in the vicinity of the repository with higher population densities than are the average for the region.	P	P	P	P	NP
Potentially adverse condition 2					
History of extreme weather phenomena—such as hurricanes, tornadoes, severe floods, or severe and frequent winter storms that could significantly affect repository operation or closure.	P	P	NP	P	NP

[a] Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

[c] All of the conditions in this table are related to one major consideration: conditions that affect transport and the significance of transport.

directly affects a site's ability to meet the requirements of the preclosure system guideline on radiological safety. In terms of the significance of transport, the doses delivered to the maximally exposed person beyond the boundaries of the site are estimated to be well within the limits of 40 CFR 191 for each site. The estimate is based partly on estimates of radionuclide releases to unrestricted areas; at each site, these releases would be within the limits specified by the NRC in 10 CFR Part 20. A summary of the evaluation for each site follows.

For the Davis Canyon site, representative offsite data indicate that relatively high mixing heights and moderate average wind speeds prevail. Dispersion may be hampered by the rugged surrounding terrain, and local inversions (about 39 episode-days per year) can cause air to be trapped in valleys. The prevailing wind directions at the site are from the southwest. The only population concentration in the downwind direction within 50 miles of the site is La Sal Junction, which is 19 miles away.

For the Deaf Smith site, representative offsite data indicate that neutral atmospheric stability conditions and high average wind speeds predominate, resulting in relatively good dispersion conditions. The prevailing mixing level, the infrequent occurrences of stagnation episodes, and the generally flat terrain at the site also favor dispersion. The prevailing wind directions at the site are from the southwest. The nearest population concentrations in the downwind direction are Masterson and Exell, which are both about 50 miles away.

The data recorded at the Hanford Meteorological Station indicate that dispersion conditions at the Hanford site are generally good. Favorable conditions include moderate average wind speeds and deep mixing levels. The prevailing wind directions are from the northwest. The Tri-Cities area (Richland, Kennewick, and Pasco) is 22 to 28 miles from the site in the predominant downwind direction.

Representative offsite data used for the analysis indicate that atmospheric stability and average wind-speed conditions favor fair to good dispersion. Mixing-level heights, the relative infrequency of stagnation episodes, and the flat to rolling terrain also favor good dispersion. The prevailing wind directions at the site are from the south and southeast. The nearest large population concentrations located in the downwind direction are Laurel and Bay Springs, which are 24 and 40 miles, respectively, from the site.

Meteorological data recorded at Yucca Flat indicate that wind velocities, atmospheric stability, and mixing heights at the site should provide effective atmospheric dispersion. Topographic conditions should also favor dispersion. The nearest population concentrations are Beatty, which is 19 miles to the west, and Amargosa Valley, which is 14 to 28 miles south of the site. Beatty and Amargosa Valley are downwind of the site less than 5 percent and about 10 percent of the time, respectively.

Extreme-weather phenomena. This major consideration addresses the historical frequency and intensity of extreme-weather phenomena--such as hurricanes, tornadoes, floods, and winter storms--that could have a significant effect on repository operation or closure. It relates to the

concern in the qualifying condition with meteorological conditions that could lead to unacceptable levels of exposure to persons in unrestricted areas. It is derived from the second potentially adverse condition of the meteorology guideline. This consideration is less important than the first major consideration because, unlike atmospheric transport characteristics, which tend to reflect prevailing meteorological conditions, extreme-weather phenomena are episodic conditions. A summary of the evaluation for each site follows.

Hurricanes are not known to occur in the Davis Canyon site area, and tornadoes are unlikely. The area is not subject to heavy snowfalls, but snowfalls greater than 1 inch occur 10 to 20 days per year. Local flooding or local heavy fog may occur about 8 days per year.

Extreme weather such as local flooding, hurricanes, tornadoes, freezing rain, and heavy fog occur in the area of the Deaf Smith County site about 29-31 days per year. The area also experiences dust storms with winds exceeding 65 mph. There are usually snowstorms less than one day per year.

Extreme-weather conditions occur infrequently at the Hanford site. Tornadoes are rare, and severe winter storms are seldom experienced.

Local flooding, hurricanes, tornadoes, and heavy fog occur in the Richton site area 30 to 70 days a year. Freezing rain, high winds, or snowstorms usually occur less than one day per year.

The frequency of extreme weather at the Yucca Mountain site is among the lowest in the nation. High winds, snowfall, and tornadoes are rare, and the area does not experience severe local flooding. Sandstorms are common, but they would rarely be severe enough to disrupt repository operation.

Summary of comparative evaluation

The Yucca Mountain site is the most favorable under the meteorology guideline. Meteorological data from Yucca Flat suggest that good dispersion conditions are likely to prevail at the site. Prevailing winds would not be likely to preferentially transport radionuclides toward population concentrations. The Yucca Mountain area has a low frequency and magnitude of extreme weather. Meteorological data from the Hanford Site show good dispersion conditions and a low incidence of extreme weather. The favorability of the Hanford site is reduced by the presence of major population centers in the prevailing downwind direction. The Deaf Smith and the Richton sites are both expected to have good dispersion characteristics. Their favorability is reduced in comparison to the Hanford site because they experience more severe weather. Davis Canyon is the least favorable for meteorology. The favorability of this site is reduced by the presence of a population center in the prevailing downwind direction, reduced dispersion conditions, and a greater frequency of severe weather.

7.3.1.1.4 Offsite installations and operations

The qualifying condition for the preclosure guideline on offsite installations and operations is as follows:

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

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-12), two major considerations influence a site's favorability with respect to the qualifying condition. These major considerations, in order of decreasing importance, are (1) the presence of nearby nuclear installations or operations and (2) the presence of nearby hazardous installations or operations.

Evaluation of sites in terms of the major considerations

Nearby nuclear installations or operations. This major consideration addresses radionuclide releases from atomic-energy defense activities and nuclear installations regulated by the NRC, which could, together with operational releases from the repository, subject the general public to radionuclide exposures above allowable limits. The evaluation accounts for the proximity of nuclear installations and operations to the site and the levels of radionuclide releases that could be expected during accidents and routine operating conditions at these installations. This consideration is derived from the favorable condition and the second potentially adverse condition. It relates directly to the qualifying condition's concern with the potential contribution of other nuclear facilities to radionuclide releases from the repository. This major consideration is assigned greater importance than nearby hazardous installations in this evaluation because of the primary focus in the qualifying condition on compliance with regulations on releases.

In evaluating this consideration, the term "nearby" for offsite installations and operations is defined as the area within 5 miles of the site. The assessment of potential cumulative impacts considers nuclear facilities within 50 miles. A summary of this consideration for each site follows.

At the Davis Canyon site, the only nearby nuclear operations are three uranium mills, which are 36 to 58 miles from the site. The combined radionuclide releases from the uranium mills and a repository at the site would be significantly lower than the specified limits.

Table 7-12. Guideline-condition findings by major consideration—offsite installations and operations[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: NEARBY NUCLEAR INSTALLATIONS OR OPERATIONS					
Favorable condition 1					
Absence of contributing radioactive releases from other nuclear installations and operations that must be considered under the requirements of 40 CFR 191, Subpart A.	NP	NP	NP	P	P
Potentially adverse condition 2					
Presence of other nuclear installations and operations, subject to the requirements of 40 CFR Part 190 or 40 CFR 191, Subpart A, with actual or projected releases near the maximum value permissible under those standards.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 2: NEARBY HAZARDOUS INSTALLATIONS OR OPERATIONS					
Potentially adverse condition 1					
The presence of nearby potentially hazardous installations or operations that could adversely affect repository operation or closure.	NP	P	P	P	P

[a] Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

The Deaf Smith site is 48 miles from the Pantex Plant, a major atomic energy defense facility near Amarillo. Releases from this plant are predicted to be only a small fraction of the specified limits and would not significantly contribute to radionuclide levels in the vicinity of the repository. There are no other nuclear facilities in the vicinity.

Commercial nuclear facilities near the Hanford site include one operating nuclear power plant of the Washington Public Power Supply System, commercial site for the disposal of low-level radioactive waste, and a plant that fabricates nuclear fuel. The predicted releases from these facilities are substantially less than the maximum permissible value and would not contribute significantly to radionuclide levels in the vicinity of the repository. DOE-owned nuclear facilities near the repository site include a plutonium-production reactor, the Purex reprocessing plant, and a reactor for testing breeder reactor fuels and components. The postulated worst-case accident at these facilities would result in a radiation exposure at the boundary of the Hanford Site that would be below applicable limits.

The Richton site has no nearby nuclear facilities, nor are there any facilities subject to 40 CFR Part 190 or 40 CFR Part 191, Subpart A, within 50 miles of the site.

At the Yucca Mountain site, there are no nearby nuclear facilities that are subject to 40 CFR Part 190 or 40 CFR Part 191, Subpart A. Potential sources of radionuclide emissions in the area are a commercial site for low-level-waste disposal about 19 miles west of Yucca Mountain, and the research with spent fuel at the Nevada Research and Development Area, which is adjacent to the east side of Yucca Mountain. The releases resulting from the postulated worst-case accident at these facilities would culminate in total radiation releases at the Nevada Test Site boundary below applicable limits. Most of the radioactive emissions from underground nuclear testing at the Nevada Test Site are contained.

Nearby hazardous installations or operations. This major consideration addresses the possible adverse effects of nearby hazardous operations and installations on repository siting, construction, operation, closure, or decommissioning. Such operations and installations could include chemical plants; fuel production, refining, transportation, and storage facilities; pipelines; major transportation routes used that could carry hazardous materials; air traffic associated with nearby airports; military operations areas; toxic materials handling facilities; and sites for hazardous-waste disposal. These facilities or operations are considered hazardous if they could affect repository operations or worker safety. Potential hazards could include shock waves from explosions, incendiary fragments, and flammable or toxic vapor clouds. This major consideration is derived from the first potentially adverse condition. It relates directly to the concern in the qualifying condition with adverse impacts of nearby hazardous installations and operations on repository operation or closure. A summary of the evaluation for each site follows.

At Davis Canyon, there are no hazardous installations within 5 miles. The site is more than 35 miles from the airports at Blanding and Monticello and more than 18 miles from the San Juan County airport. The nearest State

highway is more than 5 miles from the site. Therefore, there are no hazardous installations or operations that are likely to affect a repository at Davis Canyon.

At the Deaf Smith County a 4-inch natural-gas pipeline passes within 3,000 feet of the restricted area, but it does not constitute a hazard to a repository. U.S. Highway 385 passes within 3 miles of the site. Trucks using this highway may carry hazardous cargoes that could affect the repository in a serious transportation accident.

Potentially hazardous installations and operations in the vicinity of the Hanford site include national defense and waste-management facilities. Potentially hazardous facilities include a plutonium-production reactor, a reprocessing plant within 1.8 miles of the site, and a reactor for testing breeder reactor fuels and components within 12 miles of the site. A serious accident at any of these facilities would disrupt repository operations.

The Richton site has several nearby potentially hazardous installations and operations. The Richton Airport is within 3 miles of the site, but the probability of an air crash at the site is extremely low. A portion of the restricted airspace of the DeSoto Military Operations Area is within 5 miles. Future expansion or a more intensive use of the restricted airspace could increase the risk of an airplane crash. A 16-inch underground gas pipeline passes 1 mile from the site, but it does not constitute a credible hazard to a repository. There are two producing oil fields within 3 miles of the site. Explosions or fires at these facilities are unlikely to affect a repository at the site. State Highways 42 and 15 pass within 2 and 3 miles of the site, respectively. These highways could be used for hazardous cargoes. The nearest railroad is more than 12 miles from the Richton site.

The Yucca Mountain site has several nearby hazardous installations and operations, including the underground testing of nuclear devices, an Air Force range, and the Nevada Research and Development Area. Underground testing of nuclear weapons occurs about 10 to 20 times per year at the Nevada Test Site, which is more than 24 miles from Yucca Mountain. Some of this testing might require that underground repository activities be temporarily suspended. The Yucca Mountain site occupies a small portion of the Nellis Air Force Range, which is used for aircraft overflights but not as a target area. The only potential hazard from these overflights is the very remote chance that an airplane carrying ordinance could crash at Yucca Mountain. Research with spent fuel is performed at the Nevada Research and Development Area, which includes a major portion of Yucca Mountain. (The spent fuel is tentatively scheduled for removal in 1986.) However, these research activities are not likely to affect repository operations.

Summary of comparative evaluations

The Davis Canyon and the Richton sites are the most favorable for the guideline on offsite installations and operations. There are no nuclear facilities or other facilities subject to 40 CFR Part 190 or 40 CFR Part 191, Subpart A, located within 50 miles of the Richton site. Potentially hazardous facilities near the site include a major State highway, a gas pipeline, an oil

field, an airport, and restricted airspace associated with Camp Shelby. However, these facilities detract less from a site's favorability than a nearby nuclear installation would. At Davis Canyon, the only potential sources of radioactive emissions in the area of the site are three uranium mills. Radionuclide releases from these facilities would not contribute significantly to releases from a repository. There are no nearby hazardous installations or operations that are likely to pose a credible risk to a repository. The Deaf Smith site is slightly less favorable. The only potential source of radioactive emissions is the Pantex plant, but the contributions from this plant are not expected to be significant. Potentially hazardous installations and operations near the site include a major U.S. Highway. There are no nuclear facilities subject to 40 CFR Part 190 or Part 191, Subpart A, located near the Yucca Mountain site. Nonetheless, several potential sources of radioactivity that reduce its favorability are within 50 miles, including nuclear weapons testing and radioactive-waste disposal. The Hanford site is the least favorable for this guideline: there are potentially hazardous national defense facilities or other facilities subject to 40 CFR Part 190 near the Hanford site that could affect repository operations.

7.3.1.2 Preclosure system guideline for radiological safety

The preclosure system guideline for radiological safety requires that any projected radiological exposures of the general public and any projected releases of radioactive materials to restricted and unrestricted areas during repository operation and closure shall meet the applicable requirements set forth in 10 CFR Part 20, 10 CFR Part 60, and 40 CFR 191, Subpart A. The evidence does not support a finding that any of the sites is not likely to meet this qualifying condition.

The pertinent system elements are (1) the site-specific characteristics that affect radionuclide transport through the surroundings; (2) the engineered components whose function is to control releases of radioactive materials; and (3) the people who, because of their location and distribution in unrestricted areas, may be affected by radionuclide releases. This guideline is assigned the greatest importance among the preclosure system guidelines because it is directed at protecting both the public and the repository workers from exposures to radiation. To provide a comparative context for understanding the evaluation for this preclosure system guideline in Chapter 6, a brief summary of the evaluation of each of the sites with respect to the pertinent system elements is presented below.

With the exception of meteorological conditions, the Davis Canyon site has favorable characteristics for preclosure radiological safety. From an integrated-system viewpoint, atmospheric dispersion conditions that could be poor at times are not likely to prevent compliance with the radiation protection requirements. However, radioactivity releases from a repository are predicted to be small and are expected to more than compensate for the less than favorable atmospheric dispersion. Modeling results indicate that no member of the public is likely to receive an annual whole-body dose of more than 1.3 millirem during the construction period or more than 1.8 millirem

in any year during the operational period. On comparing these values with the regulatory limits (40 CFR Part 191) of 25 millirem per year to the whole body or approximately 140 millirem per year from natural background radiation, it appears that a repository can be located and operated at the Davis Canyon site with insignificant radiological risks to the public.

The Deaf Smith site also has generally favorable characteristics for preclosure radiological safety. A potentially adverse condition is that the dominant wind direction is from the south, and the city of Vega is approximately 8 miles to the north. However, the radioactive releases from the repository are predicted to be very small, and therefore compliance is likely. Modeling results indicate that no member of the public is likely to receive an annual whole-body dose greater than 0.04 millirem during construction or greater than 0.17 millirem in any year from normal operations during the operational period. Comparing these values with the limits of 40 CFR Part 191 (25 millirem per year to the whole body) or with approximately 95 millirem per year from natural background, it appears that a repository at the Deaf Smith site would pose insignificant radiological risks to the public.

The Hanford site has favorable characteristics pertinent to preclosure radiological safety. The meteorological conditions in the area show good atmospheric dispersion and infrequent occurrences of extreme weather. Moreover, there are no permanent residents at the site. Because of the very small radionuclide releases from the repository, the low population density in the surrounding area and the distance from the repository to highly populated areas, routine repository operations would not be expected to exceed the regulatory limits for the exposure of the general public to radiation. The individual radiation doses from other operations in the vicinity of the Hanford Site are greater than that projected for the repository. These doses are monitored and are within applicable Federal standards.

At the Richton Dome, the site characteristics that are pertinent to preclosure radiological safety are generally favorable except for meteorological conditions, which could be poor at times, with occasional stagnant conditions. From an integrated-system viewpoint, these conditions are not likely to prevent compliance with the radiation-protection requirements. Radioactive releases from a repository are predicted to be very small, which would more than compensate for the less-than-favorable atmospheric dispersion conditions. Modeling results indicate that no member of the public is likely to receive an annual whole-body dose greater than 0.41 millirem during the construction period. A comparison with the limits of 40 CFR Part 191 (25 millirem per year to the whole body or approximately 10 millirem per year from natural background radiation), it appears that a repository at the Richton site can be operated without significant radiological risks to the public.

At Yucca Mountain the meteorological characteristics favor the ability of the site to limit exposure to radiation among workers and the public; the distribution of people who live outside the area would also restrict exposures. Estimates of both the extreme worst-case accidental radiological exposures to the general public and the exposures due to normal operation are below the limits specified in 10 CFR Part 20 (1984), 10 CFR Part 60 (1983),

and 40 CFR 191, Subpart A (1985). Estimated releases under normal repository operation (Section 6.4.1) produce radionuclide concentrations that are well below the maximum permissible concentrations.

The evidence does not support a finding that any of the sites is not likely to meet the qualifying condition for preclosure radiological safety.

7.3.2 ENVIRONMENT, SOCIOECONOMICS, AND TRANSPORTATION

7.3.2.1 Technical guidelines

Three technical guidelines are associated with the preclosure system guideline on environmental quality, socioeconomics, and transportation. Their objective is to ensure that the public and the environment are protected from the effects of repository construction, operation, closure, and decommissioning.

7.3.2.1.1 Environmental quality

The qualifying condition for the environmental quality guideline is as follows:

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

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-13), four major considerations are identified that influence the favorability of the sites with respect to the qualifying condition. These major considerations are (1) the ability to meet applicable environmental requirements, (2) the ability to mitigate environmental impacts, (3) the absence of protected Federal resource areas as well as threatened and endangered plant and animal species, and (4) the absence of protected State or regional resource areas, Native American resources, and cultural sites. As a group, major considerations 1 and 2 are more important than major considerations 3 and 4, but the factors within each group are considered to be of equal importance.

Evaluation of sites in terms of the to major considerations

Ability to meet applicable environmental requirements. This major consideration addresses the procedural and substantive requirements of environmental regulations with which the repository must comply. It addresses

Table 7-13. Guideline-condition findings by major consideration--environmental quality[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: ABILITY TO MEET APPLICABLE ENVIRONMENTAL REQUIREMENTS					
Favorable condition 1					
Projected ability to meet, within time constraints, all Federal, State, and local procedural and substantive environmental requirements applicable to the site and the activities proposed to take place thereon.	NP	NP	P	NP	P
Potentially adverse condition 1					
Projected major conflict with applicable Federal, State, or local environmental requirements.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 2: ABILITY TO MITIGATE ENVIRONMENTAL IMPACTS					
Favorable condition 2					
Potential significant adverse environmental impacts to present and future generations can be mitigated to an insignificant level through the application of reasonable measures, taking into account programmatic, technical, social, economic, and environmental factors.	NP	NP	P	NP	P
Potentially adverse condition 2					
Projected significant adverse environmental impacts that cannot be avoided or mitigated.	P	NP	NP	NP	NP
MAJOR CONSIDERATION 3: PROTECTED FEDERAL RESOURCE AREAS					
Potentially adverse condition 3					
Proximity to, or projected significant adverse environmental impacts of the repository or its support facilities on, a component of the National Park System, the National Wildlife Refuge System, the National Wild and Scenic Rivers System, the National Wilderness Preservation System, or National Forest Land.	P	NP	NP	P	NP
Potentially adverse condition 6					
Presence of critical habitats for threatened or endangered species that may be compromised by the repository or its support facilities.	NP	NP	NP	NP	NP

Table 7-13. Guideline-condition findings by major consideration—environmental quality[a,b] (*continued*)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 4: PROTECTED STATE OR REGIONAL RESOURCE AREAS, NATIVE AMERICAN RESOURCES, CULTURAL SITES					
Potentially adverse condition 4					
Proximity to, and projected significant adverse environmental impacts of the repository or its support facilities on, a significant State or regional protected resource area, such as a State park, a wildlife area, or a historical area.	P	NP	NP	NP	NP
Potentially adverse condition 5					
Proximity to, and projected significant adverse environmental impacts of the repository and its support facilities on, a significant Native American resource, such as a major Indian religious site, or other sites of unique cultural interest.	NP	NP	NP	NP	NP

[a] Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

applicable site-specific regulations at the Federal, State, and local levels. A site's standing against this consideration is determined by evaluating the degree to which repository activities will comply with requirements as well as the ability to do so within specific time constraints. This consideration relates directly to the qualifying condition and the first favorable and potentially adverse conditions, which address the ability to comply with environmental requirements within time constraints. Because compliance with environmental requirements is a measure of the ability to protect the environment at a site, this consideration is a direct indicator of a site's ability to meet the qualifying condition for environmental quality. Table 6-2 and Table 6-3 in each EA (Table 6-9 and Table 6-10 in the Yucca Mountain EA) summarize actions that are planned at the sites to ensure they comply with applicable requirements and review their ability to meet each requirement. A summary of the evaluation for each site follows.

The Davis Canyon site is expected to meet all potentially applicable environmental requirements. However, it may not be possible to do so within time constraints because of uncertainties about the time required to obtain certain permits, such as those required under the Utah Air Conservation Act.

The Deaf Smith site is expected to meet all potentially applicable environmental requirements. However, it may not be possible to do so within time constraints because of uncertainties regarding the time required to comply with requirements like the Texas Drilled and Mined Shaft Act.

The Hanford site is an area that has been dedicated to nuclear activities since 1943. The environmental requirements are known for the area, and it is expected that the site will be able to meet the potentially applicable environmental requirements within time constraints.

The Richton and Yucca Mountain sites are expected to meet all potentially applicable environmental requirements, but the Richton site may not do so within time constraints because of uncertainties regarding the time to obtain certain permits.

Ability to mitigate environmental impacts. This consideration evaluates the significance of the environmental impacts of the repository and accounts for the degree to which impacts can be mitigated. It also considers features of the mitigation measures, such as their time requirements and technological feasibility, and the social, economic, or environmental factors that affect their applicability to a particular site. This consideration relates directly to the qualifying condition and the second favorable and potentially adverse conditions, which address the ability to mitigate impacts at each site. Because of its direct relevance to the qualifying condition, the environmental-impact consideration is a direct indicator of a site's ability to meet the qualifying condition for the environmental-quality guideline. A summary of the evaluation for this consideration for each site follows.

It is projected that all potentially significant impacts at the Davis Canyon site can be avoided or mitigated to an acceptable level. However, extensive mitigation measures would be required because of the close proximity of Canyonlands National Park. Although it is projected that all applicable environmental impact standards can be met, some impacts cannot be mitigated to insignificant levels. For example, construction and operation noise will be audible within Canyonlands National Park, and access corridors and facilities

will be visible from the Park. Night-sky glow from project lighting may also be visible within the Park.

It is projected that all potentially significant impacts at the Davis Canyon site can be avoided or mitigated to an acceptable level and all applicable environmental standards can be met. However, extensive mitigation measures would be required because of the close proximity of Canyonlands National Park. Furthermore, some impacts cannot be mitigated to insignificant levels. For example, construction and operation noise will be audible within the Canyonlands National Park, and access corridors and facilities will be visible from the Park. Night skyglow from repository lights may also be visible within the Park.

At the Deaf Smith site, it is projected that all potentially significant impacts can be avoided or mitigated to an acceptable level and that all applicable environmental standards can be met. However, some impacts cannot be mitigated to insignificant levels. For example, about 5,760 acres of farmland will be permanently removed from production.

At the Hanford site, all potentially significant impacts can be avoided or mitigated to insignificant levels. No noise or air-quality impacts are expected outside the boundary of the larger Hanford Site, and no impacts are projected for the Columbia River. Potential impacts associated with offsite developments will be mitigated through siting and engineering measures.

At the Richton site, it is projected that all potentially significant impacts can be avoided or mitigated to an acceptable level, and that all applicable environmental standards can be met. However, some impacts cannot be mitigated to insignificant levels. The repository will be visible, and noise will be audible in offsite areas.

It is projected that all potentially significant impacts at the Yucca Mountain site can be avoided or mitigated to insignificant levels. Air-quality impacts at the controlled-area boundary will be maintained within the limits specified in applicable regulations. Releases of radioactivity from naturally occurring material will increase during the excavation of the underground facility, but they are not expected to be significant.

Protected Federal resource areas. This consideration relates directly to the third and sixth potentially adverse conditions. It addresses the following Federal lands that are identified in these conditions: the National Park System, the National Wildlife Refuge System, the National Wild and Scenic Rivers System, the National Wilderness Preservation System, and National Forest Land, as well as designated critical habitats for threatened or endangered species. The evaluation of sites for this consideration is based on their proximity to, and the degree of projected impacts on, the listed areas, except for critical habitats. Critical habitats are considered on the basis of whether they could be compromised by the repository. Because this consideration addresses the protection of environmental quality in terms of a subset of environmental conditions (i.e., specifically identified resource areas), it is relatively less important in the overall evaluation of sites than the first two considerations. A summary of the evaluation for each site follows.

The repository operations area at the Davis Canyon site is within 1 mile of the eastern boundary of the Canyonlands National Park and is considered to be proximate to the Park. Impacts on the park include increased suspended particulate and nitrogen oxides, increased noise levels, visibility of repository facilities, temporarily disrupted access, and night skyglow. There are no known or designated critical habitats for threatened or endangered species that could be compromised by the repository or its support facilities, although there are crucial riparian habitats.

The Federal resource area nearest to the Deaf Smith site, the Buffalo Lake National Wildlife Refuge, is 22 miles from the site. No significant adverse impacts are projected for this resource. There are no critical habitats for threatened or endangered species within the site or site vicinity that could be compromised by the repository or its support facilities.

The Hanford site is on Federal land not designated for protection. The site is 4 miles from the Saddle Mountains Wildlife Refuge (a multipurpose area of the Hanford Site) and 16 miles from the McNary National Wildlife Refuge. No significant adverse impacts are projected for these wildlife refuges. No federally recognized threatened or endangered species are known to inhabit the Hanford site, though several species (e.g., the bald eagle and the peregrine falcon) have been sighted within the site. Three species of birds that are candidates for designation as threatened or endangered nest within or near the site.

The Richton site is 2.5 miles from the DeSoto National Forest, but no significant adverse impacts are projected for the forest. There are no known or designated critical habitats for threatened or endangered species that could be compromised by the repository or its support facilities.

At the Yucca Mountain site, the northern part of the controlled area is 5 miles from the Timber Mountain Caldera National Natural Landmark, which lies within the Nellis Air Force Range and the Nevada Test Site. The Toiyabe National Forest is about 50 miles from the site, and the Death Valley National Monument is 20 to 25 miles from the site. The rail line to the site will pass within several miles of the Desert National Wildlife Range, parts of which are suitable for inclusion in the Wilderness Preservation System. There are no critical habitats at the Yucca Mountain site. Ash Meadows, which contains several protected species, is about 25 miles away. No significant adverse impacts are projected for any designated Federal lands or protected species.

Protected State or regional resource areas, Native American resources, and cultural sites. This consideration relates directly to the fourth and fifth potentially adverse considerations. The fourth potentially adverse condition identifies three significant State or regionally protected resource areas: State parks, wildlife areas, and historical areas. The fifth potentially adverse condition requires an evaluation of significant Native American resources, such as religious sites, and other sites of unique cultural interest. The evaluation addresses the combined effects of a site's proximity to resource areas and the projected level of impact on those areas. Because this consideration addresses the protection of environmental quality in terms of a subset of environmental conditions (i.e., specific resource areas), it is equal in importance to the third consideration but less important than the first two considerations. A summary of the evaluation for each site follows.

The Newspaper Rock State Historical Monument is near Utah State Highway 211, 17 miles from the Davis Canyon site. The petroglyph panel at Newspaper Rock is a significant cultural resource and is listed on the National Register of Historic Places. The increased traffic flow past the Monument that would be associated with a repository at Davis Canyon will disrupt some visitation and overnight camping at the Monument. The nearest State park is the Dead Horse State Park, which is 30 miles away. The nearest significant Native American resource or site of unique cultural interest is the Salt Creek Archaeological District, which lies along the eastern edge of the Canyonlands National Park. Impacts of the repository and support facilities on these resources are not expected to be significant.

The State protected resource nearest to the Deaf Smith site is the Palo Duro Canyon State Park, located 44 miles away. Since no significant State, regional, or Native American resources are known to be present in the area of the site, no significant adverse impacts are expected.

A repository at the Hanford site would not affect any protected resource area. There are no known significant State, regional, or Native American resources within or adjacent to the site. There are significant Native American resources along the shorelands of the Columbia River, 4 miles from the site, but no significant adverse impacts are projected for these resources.

The nearest State or regionally protected resource to the Richton site is the Paul E. Johnson State Park, which is 20 miles away. The park is not expected to experience any significant adverse impacts. There are no significant Native American resources or cultural sites recorded at the Richton site, and the potential for discovering such resources is considered low.

The Yucca Mountain site is not located near any State or regionally protected resource area. The rail corridor that would be constructed to the site is not projected to adversely affect any resource areas, although it will pass within 0.9 mile of the F. R. Lamb State Park. Most of the Yucca Mountain site has been surveyed for cultural artifacts. Limited investigations have identified 178 prehistoric and 6 historic sites, many of which consist of scattered debris. No major impacts are projected for any significant Native American resource or unique cultural site.

Summary of comparative evaluation

The Hanford and the Yucca Mountain sites are most favorable under the environmental-quality guideline. Both sites are expected to meet all major environmental requirements within time constraints. Adverse environmental impacts at both sites can be avoided or mitigated to insignificant levels. Since these sites are not near any protected Federal, State, or regionally protected resource, or near any significant Native American resource or site of unique cultural interest, the development of a repository at either of these sites is not projected to have significant impacts on any of these resources.

The Deaf Smith site can comply with all potentially applicable environmental requirements, but may not be able to do so within time constraints. Similarly, it is projected that adverse impacts at the site can be limited to acceptable, but not insignificant, levels. The Deaf Smith site

is favorable with regard to the third (protected Federal resource areas) and the fourth (protected State or Native American resources) major considerations because the site is not near any of the relevant resource areas and would not be expected to adversely impact such areas.

The Richton site is also expected to meet all applicable environmental requirements, although it may not be able to do so within time constraints. All adverse impacts at the site can be avoided or mitigated, but not to insignificant levels. The Richton site is less favorable than the Hanford, Yucca Mountain, and Deaf Smith sites with respect to protected Federal resource areas because of its proximity to the DeSoto National Forest. The Richton site is favorable with regard to the fourth consideration (protected State or Native American resources) because a repository at this site is not projected to cause adverse impacts on any State or regionally protected resource area, significant Native American resource, or site of unique cultural interest.

The Davis Canyon site is the least favorable for the environmental-quality guideline. It is projected that all potentially applicable environmental requirements can be met, but it may not be possible to do so within time constraints. It is also projected that adverse impacts can be mitigated to acceptable but not insignificant levels. The favorability of the Davis Canyon site is further reduced by its proximity to, and potential impacts on, the Canyonlands National Park and the Newspaper Rock State Historical Monument.

7.3.2.1.2 Socioeconomic impacts

The qualifying condition for the socioeconomics guideline is as follows:

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

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-14), six major considerations are identified that influence the favorability of the sites with respect to the qualifying condition. These major considerations are (1) potential impacts on community services and housing, (2) potential impacts on direct and indirect employment and business sales, (3) potential impacts on primary sectors of the economy, (4) potential impacts on the revenues and expenditures of public agencies, (5) the need to purchase or acquire water rights that could affect development in the area, and (6) potential social impacts. No order of importance is assigned to these six considerations. Each consideration is, in turn, influenced by a number of more-specific conditions or contributing factors, which are discussed below.

Table 7-14. Guideline-condition findings by major consideration--socioeconomics[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: POTENTIAL IMPACTS TO COMMUNITY SERVICES AND HOUSING					
Favorable condition 1					
Ability of an affected area to absorb the project-related population changes without significant disruptions of community services and without significant impacts on housing supply and demand.	NP	P	P	P	P
Potentially adverse condition 1					
Potential for significant repository-related impacts on community services, housing supply and demand, and the finances of State and local government agencies in the affected area.	P	NP	NP	NP	NP
MAJOR CONSIDERATION 2: POTENTIAL IMPACTS ON DIRECT AND INDIRECT EMPLOYMENT AND BUSINESS SALES					
Favorable condition 2					
Availability of an adequate labor force in the affected area.	NP	NP	NP	NP	NP
Favorable condition 3					
Projected net increases in employment and business sales, improved community services, and increased government revenues in the affected area.	P	P	P	P	P
Potentially adverse condition 2					
Lack of an adequate labor force in the affected area.	P	P	P	P	P
MAJOR CONSIDERATION 3: POTENTIAL IMPACTS TO PRIMARY SECTORS OF THE ECONOMY					
Favorable condition 4					
No projected substantial disruption of primary sectors of the economy of the affected area.	P	P	P	P	P
Potentially adverse condition 4					
Potential for major disruptions of primary sectors of the economy of the affected area.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 4: POTENTIAL IMPACTS TO THE REVENUES AND EXPENDITURES OF PUBLIC AGENCIES					
Favorable condition 3					
Projected net increases in employment and business sales, improved community services, and increased government revenues in the affected area.	P	P	P	P	P

Table 7-14. Guideline-condition findings by major consideration--socioeconomics[a,b] (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 4: POTENTIAL IMPACTS TO THE REVENUES AND EXPENDITURES OF PUBLIC AGENCIES (Continued)					
Favorable condition 3 (continued)					
Potentially adverse condition 1					
Potential for significant repository-related impacts on community services, housing supply and demand, and the finances of State and local government agencies in the affected area.	P	NP	NP	NP	NP
MAJOR CONSIDERATION 5: THE NEED TO PURCHASE OR ACQUIRE WATER RIGHTS THAT COULD EFFECT DEVELOPMENT IN THE AREA					
Potentially adverse condition 3					
Need for repository-related purchase or acquisition of water rights, if such rights could have significant adverse impacts on the present or future development of the affected area.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 6: POTENTIAL SOCIAL IMPACTS					
Favorable condition 1					
Ability of an affected area to absorb the project-related population changes without significant disruptions of community services and without significant impacts on housing supply and demand.	NP	P	P	P	P
Potentially adverse condition 1					
Potential for significant repository-related impacts on community services, housing, supply and demand, and the finances of state and local government agencies in the affected area.	P	NP	NP	NP	NP

[a] Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.
[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

Evaluation of the sites in terms of the major considerations

Potential impacts on community services and housing. This consideration relates to the requirement in the qualifying condition that impacts on community services or housing in affected areas and communities can be mitigated or compensated for. This consideration is derived from the first favorable condition and the first potentially adverse condition. The first favorable condition focuses on the ability of the affected area to absorb repository-related population growth without disrupting community services and the supply and demand for housing. The potentially adverse condition addresses impacts on community services and housing in communities near a potential site. Impacts on community services and housing depend on five contributing factors: population composition and density, the distribution of in-migrants, current capacity and trends in the use of community services and infrastructure, housing supply and demand, and the community's ability to accommodate growth. A site's favorability improves as the combination of these contributing factors leads to fewer impacts on community services and housing. A summary of the evaluation for each site follows.

A repository at the Davis Canyon site is likely to result in substantial impacts on community services and housing in the affected area. The projected net change in the population of Grand and San Juan Counties is expected to be approximately 20 percent above the baseline population during the peak of in-migration. This level of population increase may cause a significant disruption in housing and community services. The number of housing units needed by repository-related households could reach 1,600 units. Fewer than half this number of units are currently available in the study area. The communities of Moab, Monticello, and Blanding are projected to have peak-year cumulative growth rates of 31, 50, and 24 percent, respectively. Although this level of growth would occur over a 6-year period, it would cause significant impacts.

The development of a repository at the Deaf Smith site is not expected to result in major impacts to community services or housing. Most project in-migrants are expected to locate in Amarillo, about 40 miles from the site. Amarillo is a large urban center that has a sufficient community infrastructure to accommodate repository workers and their families. Vega, which is the closest community to the site, is projected to experience a peak-year cumulative growth of 8 percent. Since this growth would occur over a 6-year period, it is not considered to have potential for significantly disrupting the community. However, in-migration is expected to cause some minimal increase in the demand for community services (e.g., housing, schools, police protection, medical services, water supply, and recreation) in the affected area.

The Tri-Cities (Richland, Kenewick, and Pasco) have historically received most of the in-migrating work force associated with large projects at the Hanford Site. If the most likely estimate of 1,700 in-migrants for the repository is used, annual growth rates during the peak year would be less than 4 percent for all communities. These annual growth rates are low in comparison with previous levels of growth in the area. There is also a large and underused infrastructure, particularly excess housing, in the Tri-Cities area. This suggests that the development of a repository at Hanford represents an opportunity for the area to more fully use its resources. Therefore, community-services and housing impacts are projected to be favorable.

For the Richton site, the capacity of housing in counties receiving in-migrants is expected to be adequate. Because the availability of community services generally parallels the availability of housing, these services are also expected to be adequate in the affected area. At a community level, the town of Richton is projected to experience a peak-year cumulative growth of 37 percent. This growth would occur over a 4-year period. Although the average annual growth rate is higher than the 6-percent growth rate projected for Richton's baseline population, significant disruption is not expected. Nonetheless, the in-migrating population is projected to cause moderate service impacts in the study area, including the need for some additional housing, teachers, police officers, physicians, hospital beds, and water and sewage facilities.

For the Yucca Mountain site, over 80 percent of the in-migrants are expected to settle in the Los Vegas area, where the infrastructure is sufficient to accommodate them. In the rural communities closer to the site, the maximum 1-year growth rates, which are projected from the historical settlement patterns of workers at the Nevada Test Site, will be less than 5 percent for all communities near the site except Pahrump (5 percent) and Indian Springs (13.2 percent). Although demands for services and housing in communities could increase in proportion to these peak 1-year growth rates, the potential impacts would be largely confined to the service providers that are best equipped for dealing with growth. Generally, services in the unincorporated communities near the site (i.e., Indian Springs, Pahrump, Beatty, and Amargosa Valley) are provided not by town governments but by county-wide agencies that have broad tax bases, planning capabilities, and experience in responding to population growth rates within the range of those projected for the repository. With only a few exceptions, water in the unincorporated communities near the repository site is supplied by private wells, and waste water is disposed of in private septic tanks and leach fields. In addition, housing in rural southern Nevada is provided almost entirely by the private sector.

Potential impacts on direct and indirect employment and business sales. This major consideration is derived from the second and the third favorable conditions and the second potentially adverse condition. Two factors contribute to the potential for increased direct and indirect employment and business sales: repository-related needs for labor and expected local hires, and repository-related local purchases of materials. This major consideration is related to the qualifying condition in that increased local employment and business sales enhance the ability of affected areas and communities to absorb repository-related growth by increasing business and tax revenues. A site's favorability increases with repository-related economic growth. A summary of the evaluation for each site follows.

At the Davis Canyon site, a repository is expected to generate over 2,000 direct and indirect jobs at its peak, of which about 400 are expected to be filled by local residents. The repository is also expected to generate about $5.4 million per year in local purchases during the construction phase.

At the Deaf Smith site, local residents are expected to fill 1,380 of the total number of jobs at the peak of repository development. Direct local purchases of about $11.3 million per year are projected during repository construction. An additional $5.7 million per year is expected to be spent as a result of indirect effects caused by material purchases.

At the Hanford site, total employment could increase by more than 2,400 at the peak of repository development. A substantial number of these jobs will be filled locally. In addition, substantial spending through wages and on purchases of materials from local suppliers is expected.

At the Richton site, the repository is expected to generate about 1,300 jobs for local residents at the peak of its development. In addition, about $5.3 million in direct local material purchases will be made during repository construction.

For the Yucca Mountain site, up to 4,800 jobs could be created during peak repository development. Many of these jobs are expected to be filled by current residents of the area. The increases in area income from wages for repository construction and operation could reach $110 million in 1998.

Potential impacts on primary sectors of the economy. The third major consideration is derived from the fourth favorable condition and fourth potentially adverse condition. The contributing factors are major sectors of the economy, employment distribution and trends by economic sector, and the compatibility of a repository with the area's economic base. The smaller any projected disruption, the greater the site's favorability. A summary of the evaluation for each site follows.

Primary sectors of the Davis Canyon study area are retail trade and services (31 percent of employment), government (24 percent of employment), and mining (14 percent of employment). Since unemployment in mining has increased significantly in the last 6 years, a repository may have a positive effect on this sector. The extent of this positive effect is unknown, because significant numbers of miners have left the area since 1983. The demands on local government created by new growth should create jobs in the government sector. In retail trade and services, tourism represents approximately 475 man-years of employment for San Juan and Grand Counties or about 24 percent of the jobs in these sectors. Because the Canyonlands National Park is near the repository, some tourists may choose to avoid the park, and some jobs related to tourism could be lost. The total number of jobs directly associated with purchases made by tourists with Canyonlands as their primary destination is approximately 76 man-years of employment. The local retail-and-service jobs directly related to local purchases associated with the repository will average 240 man-years of employment during construction and 230 man-years during operation. Therefore, while some tourism-related jobs in the retail and service sectors may be lost, other jobs are expected to be created.

The primary sectors of the Deaf Smith study area are government (18 percent), retail trade (15 percent), services (14 percent), agriculture (10 percent), and manufacturing (10 percent). It is expected that the repository will increase the need for products and services provided by the retail trade, government, and service sectors. No substantial loss of employment due to the repository is expected for the agricultural or manufacturing sectors because most of their markets are outside the region of the site. However, the sales of health foods and bottled water could decline. In addition, projected impacts on the agricultural sector include a loss of more than $1.6 million in crop and livestock revenues at the peak of construction (about 0.12 percent of the expected crop and livestock revenues in the region in 1997); a loss of $1.7 million in crop and livestock revenues at the peak of operation; a loss of $2.5 million and $3.0 million in agricultural business during the peak of

repository construction and operation, respectively; and a loss of 0.61 percent of the productive land in Deaf Smith County.

In the affected area of the Hanford site, the potential for major disruptions of primary sectors of the economy is very small. The primary sectors of employment are the Washington Public Power Supply System and its contractors, the DOE and its contractors, and agriculture. A repository at the Hanford site would probably stabilize economic conditions and employment in the area.

In the affected area of the Richton site, the primary economic sectors are manufacturing (21 percent), government (25 percent), and retail trade (22 percent). The repository is not expected to affect markets for manufactured goods. Employment in the trade and government sectors is likely to increase because of increases in wages, local purchases, business sales, and demands for services.

The primary sectors of the economy in southern Nevada are mining and tourism. A repository at Yucca Mountain is expected to increase the number of mining jobs in Nye County. In regard to tourism, even though repository-related increases in population may have a small positive effect, only potential negative impacts have been investigated to date. Preliminary results of an ongoing evaluation are inconclusive. Studies of the effects of well-publicized accidents have yielded no evidence of long-term effects on tourism.

Potential impacts on public agency revenues and expenditures. This consideration is derived from the third favorable condition and the first potentially adverse condition, which addresses the potential for increased revenues, and the net fiscal balances of State and local government agencies, respectively. This consideration relates to the qualifying condition in that the DOE must be able to mitigate adverse economic impacts, including impacts on the finances of State or local governments. Impacts on the revenues and expenditures of public agencies depend on three contributing factors: the sources of, and trends in, the expenditures and revenues of local government; the additional needs for community services induced by the repository project; and economic growth in the area and resulting increases in tax revenues. A site's favorability increases as the repository more positively affects State and local finances and decreases as more mitigation of fiscal impacts is required. A summary of the evaluation for each site follows.

At the Davis Canyon site, a repository will increase the revenues collected through property taxes, sales taxes, and user fees. These increases in revenues, however, may not offset increases in outlays for community services and infrastructure needs.

At the Deaf Smith site, the repository will also increase the revenues collected in property taxes, sales taxes, and user fees. These increases in revenues are expected to offset the projected minimal impacts on community services.

At the Hanford site, the State or local governments will not experience significant adverse fiscal impacts. There are virtually no projected impacts

on community services, and there are some economic benefits that will result in additional tax revenues.

The potential impact on the revenues and expenditures of public agencies affected by the Richton site is similar to that at the Deaf Smith site. Revenues from property taxes, sales taxes, and user fees are likely to increase. These revenue increases are expected to offset increases in expenditures due to changes in service requirements.

At the Yucca Mountain site, significant repository-induced expenditures are expected to result in increased State and local tax revenues, which may be offset by additional outlays in the study area.

Need to purchase or acquire water rights that could affect development in the area. This major consideration is derived from the third potentially adverse condition (see Table 7-14). The need to acquire water rights depends on two contributing factors: project-related water requirements and current water rights, use, and capacity. Specifically, the greater the competition for water at the site and the more the DOE's acquisition of water rights could affect development in the area, the lower the site's favorability. A summary of the evaluation for each site follows.

At the Davis Canyon site there is a variety of potential water sources. A likely source of water is the San Juan County Water Conservatory District, which has jurisdiction over the site. The Conservatory District has indicated that it would enter into an agreement for the annual sale or lease of up to 2,800 acre-feet of water from the Colorado River or one of its tributaries during construction and up to 500 acre-feet during the operation of the repository. Because the San Juan Planning Council expects that two new reservoirs that are being built in the Blanding and Monticello area will supply enough water for future needs and because the Council is willing to sell or lease part of its own appropriation, development in the area should not be affected.

The Ogallala aquifer, the major source of water for municipal use and irrigation in the Texas Panhandle and in the area of the Deaf Smith site, is being depleted. The Texas Water Commission predicts that only part of the projected water requirements for irrigated agriculture in 1990 will be met under a high-demand scenario. Although a repository at the Deaf Smith site will require relatively little water to operate in comparison with other industrial users in Texas and less than one-fourth of one percent of projected water supply in the County throughout the life of the repository, the water requirements of the repository will further deplete the aquifer and may compete with other users, especially agricultural users. Municipal and industrial water requirements are expected to be met because these users are able to pay the higher prices associated with more a limited supply.

The Federal Government already owns the water rights that are needed for a repository at the Hanford site. Water will be supplied from the Columbia River by an existing pump station. No significant impacts on municipal water systems in the study area are expected because there is excess capacity in the Tri-Cities area, where most in-migrants would live.

At the Richton site, the DOE will not need to acquire water rights because ground water is expected to be available at the site. In addition, no planned developments in the study area have been identified that would be adversely affected by the water use projected for the repository.

It is projected that sufficient water for a repository at Yucca Mountain can be obtained from new or existing wells at the Nevada Test Site, for which the DOE has existing water rights. For local water systems, secondary impacts due to the increased demand associated with population increases are expected to be minimal, although some communities may require mitigation assistance to expand their water systems to meet the needs of new in-migrants. There are no major developments or population centers that will compete with the repository for ground water. The Las Vegas Valley is projected to have water-supply problems by the year 2020 with or without the population increases resulting from the development of the repository.

Potential social impacts. This major consideration relates directly to the requirement in the qualifying condition that significant social impacts on communities and surrounding areas can be offset by reasonable mitigation or compensation. It also relates to the first favorable and potentially adverse conditions, which address the quality of life by focusing on impacts to community services and the finances of State and local government agencies. Three factors contribute to the potential for social impacts: the quality of life and existing social problems in the affected communities, the size of the in-migrating population in comparison with the existing population, and the compatibility of the in-migrating population with the lifestyles and characteristics of the current residents. The more compatible the in-migrating population with the current population and the fewer the disruptions that it causes, the greater the site's favorability. A summary of the evaluation for each site follows.

At the Davis Canyon site, it is estimated that Moab and Blanding will experience an increase of 31 and 24 percent, respectively, in population during the first 6 years of the repository. Monticello is expected to grow by about 50 percent during the same period. These increases would be dramatic and could lead to conflicts between long-time residents and newcomers over leadership positions. Rapid growth could also contribute to increases in alcohol and drug abuse, crime, and family conflict.

At the Deaf Smith site, Vega is expected to receive an 8-percent increase above the baseline population. On the basis of this population increase, Vega could experience some social changes. The lifestyles of construction workers may not be compatible with long-time residents, though most workers are expected to live in Amarillo or Hereford. Major conflicts over leadership positions between long-term residents and newcomers are not expected.

At the Hanford site, a repository will make a small but positive contribution to the recovery of the area from the decline of the early 1980s. The effect of any impacts on social conditions is likely to be positive. Since expected in-migrating work force is small in comparison with the projected baseline population, serious social disruptions are unlikely. The Yakima Indian Nation, the Confederated Tribes of the Umatilla Indian Reservation, and the Nez Perce Tribe are formally designated as affected

Indian Tribes under the Act. A repository at Hanford is not expected to cause significant social impacts on these Indian Tribes.

At the Richton site, the town of Richton is expected to receive 483 repository-related in-migrants, a 37-percent change over baseline projections for the peak year of construction. This repository-related growth for Richton is significant and will probably cause social changes and conflicts over leadership positions in the community.

For the Yucca Mountain site, most of the in-migrating population is projected to be absorbed in Clark County. Since the size of the in-migrating population is small in comparison with the projected baseline population, and the existing social structure in urban Clark County is highly diverse, the growth-related effects on social structure are not expected to be significant. In contrast, Nye County is a rural area where experience with large energy-development projects indicates that growth-related social disruptions could occur. However, preliminary assessments suggest that in-migrating construction workers would be assimilated within the existing social structure. Historically, communities in Nye County have had a large population of miners, and mining continues to be important in the area. Therefore, because of the diversity of existing cultural environments within Nye and Clark Counties, in-migrating workers would be able to select a compatible cultural environment and are likely to be readily assimilated into the community.

Summary of comparative evaluations

The Hanford site is the most favorable for all six major considerations. The Tri-Cities has a large and under-used infrastructure, and the area would benefit from repository-related employment and increases in business sales. The economy of the affected area is largely based on nuclear activities, although there is also substantial agriculture. No significant adverse fiscal or social impacts are expected, and the DOE owns all necessary water rights.

At the Yucca Mountain site, most of the in-migrants are expected to settle in the area of Las Vegas, which has a sufficient infrastructure to accommodate them. Services in the unincorporated communities nearer the site are generally provided by county-wide organizations that are well equipped to deal with growth. Both Nye and Clark Counties are expected to benefit from increased employment and business sales. Employment in the mining industry in Nye County is expected to increase substantially. The tourist industry is not expected to be negatively affected. Public revenues will probably increase, and social impacts are expected to be small. Sufficient water for the repository can be obtained from wells at the Nevada Test Site, and secondary impacts should be minimal.

At the Deaf Smith site, population growth may cause minimal adverse impacts on community services. Vega could also experience social changes because the lifestyles of newcomers and long-time residents may be incompatible. In addition, a repository is expected to cause minor disruption to the agricultural industry in the affected area. Some water may also be diverted from other uses because the DOE will need to acquire water rights in a region where the major source of water is being depleted. The area is expected to benefit from increased employment, business sales, and tax revenues.

At the Richton site, moderate impacts on community services are projected because of the population growth associated with a repository. Local purchases and job opportunities will increase, but adverse social impacts could occur, especially in the town of Richton. Primary sectors of the economy are not expected to be disrupted, and public revenues should increase. There is no need for the DOE to purchase or acquire water rights.

A repository at the Davis Canyon site is expected to induce major adverse impacts on community services and housing; these impacts will occur in San Juan County and in three small communities near the Davis Canyon site. In addition, a significant population growth may cause substantial social impacts. Although a small number of jobs related to tourism in the retail and service sectors may also be lost, net local employment, business sales, and tax revenues should increase. Water rights are likely to be obtained from the San Juan Planning Council without affecting present or future development.

7.3.2.1.3 Transportation

The qualifying condition for the transportation guideline is as follows:

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

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-15), four major considerations are identified that influence the favorability of sites with respect to the qualifying condition. These major considerations, in order of decreasing importance, are (1) transportation safety, (2) potential for environmental disruption, (3) the cost of transportation infrastructure, and (4) the cost of transportation hardware and operations. Each of the major considerations is, in turn, influenced by several contributing factors, which are discussed below.

Evaluation of the sites with respect to major considerations

Transportation safety. Transportation to the repository will present a potential hazard, albeit small, to people living along the routes traveled. The hazards are both radiological (i.e., due to the radiological nature of the cargo) and nonradiological (i.e., due to the movement of the transport vehicle and not related to the character of the cargo). The guidelines emphasize that

Table 7-15. Guideline-condition findings by major consideration--transportation[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: THE SAFETY OF TRANSPORTING SPENT FUEL AND HIGH-LEVEL WASTE TO THE REPOSITORY					
Favorable condition 1	NP	P	P	P	P
Availability of access routes from local existing highways and railroads to the site which have any of the following characteristics:					
(i) Such routes are relatively short and economical to construct as compared to access routes for other comparably siting options.	NP	NP	P	NP	NP
(iv) Such routes are free of sharp curves or steep grades are not likely to be affected by landslides or rock slides.	NP	P	P	P	P
(v) Such routes bypass local cities and towns.	NP	P	P	NP	P
Favorable condition 2	NP	P	P	NP	P
Proximity to local highways and railroads that provide access to regional highways and railroads and are adequate to serve the repository without significant upgrading or reconstruction.					
Favorable condition 4	NP	NP	NP	NP	P
Availability of a regional railroad system with a minimum number of interchange points at which train crew and equipment changes would be required.					
Favorable condition 5	NP	NP	NP	P	NP
Total projected life-cycle cost and risk for transportation of all wastes designated for the repository site which are significantly lower than those for comparable siting options, considering locations of present and potential sources of waste, interim storage facilities, and other repositories.					
Favorable condition 8	P	P	P	P	P
Plans, procedures, and capabilities for response to radioactive waste transportation accidents in the affected State that are completed or being developed.					
Favorable condition 9	P	P	P	P	P
A regional meteorological history indicating that significant transportation disruptions would not be routine seasonal occurrences.					

Table 7-15. Guideline-condition findings by major consideration--transportation[a,b] (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: THE SAFETY OF TRANSPORTING SPENT FUEL AND HIGH-LEVEL WASTE TO THE REPOSITORY (Continued)					
Potentially adverse condition 2 Terrain between the site and existing local highways and railroads such that steep grades, sharp switchbacks, rivers, lakes, landslides, rock slides, or potential sources of hazard to incoming waste shipments will be encountered along access routes to the site.	P	NP	NP	NP	NP
Potentially adverse condition 3 Existing local highways and railroads that could require significant reconstruction or upgrading to provide adequate routes to the regional and national transportation system.	P	NP	NP	NP	NP
Potentially adverse condition 4 Any local condition that could cause the transportation-related costs, environmental impacts, or risk to public health and safety from waste transportation operations to be significantly greater than those projected for other comparable siting options.	P	NP	NP	NP	P
MAJOR CONSIDERATION 2: THE AMOUNT AND NATURE OF THE ENVIRONMENTAL DISRUPTION CAUSED BY DEVELOPING THE TRANSPORTATION NETWORK AND ACCESS ROAD (INFRASTRUCTURE) AROUND AND TO THE SITE					
Favorable condition 1 Availability of access routes from local existing highways and railroads to the site which have any of the following characteristics:	NP	P	P	P	P
(i) Such routes are relatively short and economical to construct as compared to access routes for other comparable siting options.	NP	NP	P	NP	NP
(iii) Cuts, fills, tunnels, or bridges are not required.	NP	NP	P	NP	NP
(iv) Such routes are free of sharp curves or steep grades and are not likely to be affected by landslides or rock slides.	NP	P	P	P	P
(v) Such routes bypass local cities and towns.	NP	P	P	NP	P
Favorable condition 2 Proximity to local highways and railroads that provide access to regional highways and railroads, and are adequate to serve the repository without significant upgrading or reconstruction.	NP	NP	P	NP	P

Table 7-15. Guideline-condition findings by major consideration--transportation[a,b] (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 2: THE AMOUNT AND NATURE OF THE ENVIRONMENTAL DISRUPTION CAUSED BY DEVELOPING THE TRANSPORTATION NETWORK AND ACCESS ROAD (INFRASTRUCTURE) AROUND AND TO THE SITE (Continued)					
Favorable condition 3	NP	P	P	P	P
Proximity to regional highways, mainline railroads, or inland waterways that provide access to the national transportation system.					
Potentially adverse condition 3	P	NP	NP	NP	NP
Existing local highways and railroads that could require significant reconstruction or upgrading to provide adequate routes to the regional and national transportation system.					
Potentially adverse condition 4	P	NP	NP	NP	P
Any local condition that could cause the transportation-related costs, environmental impacts, or risk to public health and safety from waste transportation operations to be significantly greater than those projected for other comparable siting options.					
MAJOR CONSIDERATION 3: THE COST OF DEVELOPING AN ADEQUATE INFRASTRUCTURE BETWEEN THE SITE AND THE NEAREST NATIONAL TRANSPORTATION NETWORK					
Favorable condition 1	NP	P	P	P	P
Availability of access routes from local existing highways and railroads to the site which have any of the following characteristics:					
(i) Such routes are relatively short and economical to construct as compared to access routes for other comparable siting options.	NP	N P	P	NP	NP
(ii) Federal condemnation is not required to acquire rights-of-way for the access rdutes.	NP	NP	P	NP	NP
(iii) Cuts, fills, tunnels, or bridges are not required.	NP	NP	P	NP	NP
(iv) Such routes are free of sharp curves or steep grades and are not likely to be affected by landslides or rock slides.	NP	P	P	P	P
(v) Such routes bypass local cities and towns.	NP	P	P	NP	P

Table 7-15. Guideline-condition findings by major consideration—transportation[a,b] (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 3: THE COST OF DEVELOPING AN ADEQUATE INFRASTRUCTURE BETWEEN THE SITE AND THE NEAREST NATIONAL TRANSPORTATION NETWORK (Continued)					
Favorable condition 2 Proximity to local highways and railroads that provide access to regional highways and railroads, and are adequate to serve the repository without significant upgrading or reconstruction.	NP	NP	P	NP	P
Potentially adverse condition 1 Access routes to existing local highways and railroads that are expensive to construct relative to comparable siting options.	P	P	NP	P	P
Potentially adverse condition 3 Existing local highways and railroads that could require significant reconstruction or upgrading to provide adequate routes to the regional and national transportation system.	P	NP	NP	NP	NP
Potentially adverse condition 4 Any local condition that could cause the transportation-related costs, environmental impacts, or risk to public health and safety from waste transportation operations to be significantly greater than those projected for other comparable siting options.	P	NP	NP	NP	P
MAJOR CONSIDERATION 4: THE COSTS ASSOCIATED WITH TRANSPORTING THE SPENT FUEL AND HIGH-LEVEL WASTES TO THE SITE					
Favorable condition 4 Availability of a regional railroad system with a minimum number of interchange points at which train crew and equipment changes would be required.	NP	NP	NP	NP	P
Favorable condition 5 Total projected life-cycle cost and risk for transportation of all wastes designated for the repository site which are significantly lower than those for comparable siting options, considering locations of present and potential sources of waste, interim storage facilities, and other repositories.	NP	NP	NP	P	NP
Favorable condition 6 Availability of regional and local carriers-truck, rail, and waste-which have the capability and are willing to handle waste shipments to the repository.	P	P	P	P	P

Table 7-15. Guideline-condition findings by major consideration--transportation[a,b] (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 4: THE COSTS ASSOCIATED WITH TRANSPORTING THE SPENT FUEL AND HIGH-LEVEL WASTES TO THE SITE (Continued)					
Favorable condition 7 Absence of legal impediment with regard to compliance with Federal regulations for the transportation of waste in or through the affected State and adjoining States.					
Favorable condition 9 A regional meteorological history indicating that significant transportation disruptions would not be routine seasonal occurrences.	P	P	P	P	P

[a] Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

the people living near the site will be most significantly affected, but they also recognize that the hazards and impacts of transporting wastes are national in scope. Because the DOE's main goal in transportation is safety, and the guidelines emphasize the role of safety, transportation safety is the most important consideration in evaluating the sites.

The transportation of radioactive materials during the past 40 years has been accomplished with an exemplary record of safety. Models that are used to estimate the radiological risks of transportation tend to generate extremely low expected-risk values for the public because they rely on historical data. When relative terms like "high" or "moderate" are used in this evaluation, they must be considered in the context of the low overall radiological risk from transportation. The nonradiological risk is calculated under the assumption that the probability of accidents for radioactive-waste shipments can be represented by accident statistics for general commerce. The DOE believes that these accident statistics will overestimate the actual number of deaths and injuries. Other factors being equal, the site with the smallest radiological hazard will also have the smallest nonradiological hazard.

Since the principal contributing factor in determining risk is the distance traveled, a better site for this consideration is one that is close to the sources of spent fuel and high-level waste. Other contributing factors that increase the favorability of sites are access and local routes that avoid population centers, flat local terrain with good visibility, and regional weather conditions that rarely cause hazardous road conditions. It should be noted that, regarding weather conditions, the DOE needs additional information before determining the comparative favorability of the sites. In contrast, less favorable sites are distant from waste sources, must be reached by routes that pass through population centers or rugged terrain, and are located in regions where weather conditions often cause hazardous road conditions. A summary of transportation risk and cost calculations is presented in Table 7-16; the reader is referred to Appendix A for more-extensive analytical results. Table 7-17 presents the factors used to evaluate disruptions of the environment and the cost of infrastructure. A summary of the evaluation for each site follows.

Davis Canyon is centrally located in the large region defined by the five nominated sites, but it is more difficult to reach because of its remote and rugged setting. Access from existing highways and railroads is extremely difficult, and there is a potential for landslides that could interrupt or jeopardize shipments. A long stretch of noninterstate highway must be traversed before reaching the site. From a national perspective, the relative risk of transporting to Davis Canyon is moderate to high, but that risk has to be considered along with the potential hazards near the site that could further reduce the overall level of safety. However, the added risk associated with hazardous local access to the site is somewhat offset by the remoteness of the site and the low population density in the area.

The Deaf Smith site is convenient to major national highways. The distance from sources of spent fuel is low to moderate, and, as shown in Table 7-16, the level of relative safety is therefore moderate to high. The terrain surrounding the site is generally flat and poses no safety hazard. The population density around the site is low to moderate.

Table 7-16. Summary of transportation risks and costs

Parameters	Davis Canyon	Deaf Smith	Hanford	Richton	Yucca Mountain
Risk[a]					
100% truck					
Radiological	9.5	7.9	12	6.3	11
Nonradiological	30	24	39	19	36
100% rail					
Radiological	0.3	0.2	0.3	0.2	0.3
Nonradiological	2.6	2.1	3.2	1.8	3.0
Number of interchanges	3	2-4	2-4	2-4	1-2
Total shipment-miles[b]					
100% truck	145.1	121.4	186.7	96.4	176.8
100% rail	25.5	21.7	33.3	17.7	31.1
Number of interchanges[c]	3	2-4	2-4	2-4	1-2
Cost[d]					
100% truck	1,305	1,127	1,615	936	1,538
100% rail	1,207	1,122	1,376	982	1,345

[a]Number of fatalities during the preclosure period.
[b]One-way million miles.
[c]Within the transportation study area.
[d]Millions of 1985 dollars.

Table 7-17. Factors used to evaluate disruption of the environment and cost of infrastructure

Parameter	Davis Canyon Truck/Rail	Deaf Smith Truck/Rail	Hanford Truck/Rail	Richton Truck/Rail	Yucca Mountain Truck/Rail
Access route					
Miles	25/38-54	1/25-35	<3/<3	4/26	16/100
Cost[a]	79/141-269	1/21-44	<6[b]	3/16	12/151
Upgrade					
Miles	64-68/0	4/0-13	0/0	23/0	0/0
Cost[a]	15-35/0	1/<10	0/0	6/0	0/0
Distance from end of access route to major highway or mainline rail	64-173/30-36	14/0-13	0/48	22/0	0/0
Need for tunnels	Yes	No	No	No	No
Need for bridges	Yes	Yes	No	Yes	Yes
Need for Federal condemnation	Yes	Yes	No	Yes	No
Terrain	Very rugged	Generally flat	Generally flat	Gently rolling	Gently sloping

[a]In millions of 1985 dollars.
[b]Total cost for truck and rail transportation.

Since the Hanford site is the most distant from the large majority of spent-fuel sources, it has the highest relative risk from a national perspective. The introduction of a second repository reduces the effect of distance on the overall transport risk (for a more complete discussion of the effect of a second repository see Appendix A, Section A.11). Transportation safety near the site is considered to be relatively high because of the flat terrain and the good existing transportation network. The population density in the area is moderate.

The Richton site is favorable for the transportation-safety consideration because it is closer to the sources of spent fuel than the other sites. National transportation risks are therefore reduced, and the relative level of transportation safety is high. The site would be more favorable if there were fewer local towns and cities were nearby; however, with the construction and upgrading of the local access routes, local safety should be high as well.

Yucca Mountain is easily accessible, but it is far from most sources of spent fuel. The local rail network that will be developed will effectively bypass Las Vegas. Local roads provide good access to the interstate highway system. One potentially hazardous feature of the access routes is their proximity to an Air Force bombing range. Although this is not expected to present a significant risk, some additional safeguarding of shipments may be required. The local terrain presents no hazards.

Environmental disruption. The second major consideration accounts for the environmental impacts caused by improving the existing infrastructure and constructing new access routes to the site. Though not as important as the first consideration, the potential for environmental disruption has much significance. For example, transportation operations and the development of access routes might adversely affect sensitive species on a large scale (over many miles), and the aesthetic quality of the region may be reduced by the construction of road and rail routes. This consideration reflects the focus in the guideline on local conditions around the site. Effects on the environment along national highways and railroads were considered when those networks were developed for regular commercial traffic. In this respect, the incremental environmental impacts of transporting radioactive waste are not considered to be significant on a national scale.

A contributing factor for this consideration is whether a site requires access routes that would disrupt the environment. Table 7-17 lists the major factors that are considered in evaluating the potential for environmental disruption. A more favorable site would be one that does not require the construction of lengthy access roads. Other qualities that would make a site better are access routes that do not conflict with current land-use plans; no requirements for cuts, fills, tunnels, or bridges; and disruptions that would affect the least number of people. A less favorable site would require significant construction of access routes through pristine or unique environmental areas. Other qualities that reduce the favorability of a site are access routes that conflict with current land-use plans; a requirement for many cuts, fills, tunnels, and bridges; and the displacement of many people by the access route. A summary of the evaluation for each site follows.

Major construction of highways and railroads would be required to reach the Davis Canyon site. This new construction would disrupt previously

undisturbed land and diminish the aesthetic quality of the area. The construction of access routes would require major cuts and fills as well as tunnels. The existing transportation network would also have to be improved.

Deaf Smith County is located on generally flat terrain that would not require major excavation during construction. Upgrading of the existing road is not expected to cause significant environmental impacts. A long segment of new track must be laid to reach the site, but the environmental disruptions would be minor.

For the Hanford site, the truck and rail access routes would be short, and little environmental disruption would result from constructing the access routes. No improvement in the existing transportation network is needed.

The Richton site is on generally flat terrain. Although a long railspur would have to be built to reach the site, it would follow an abandoned railroad right-of-way. The existing local road would have to upgraded for a significant length. A short length of new road would have to be built to reach the site. The environmental impacts of new construction are not expected to be significant.

To reach the Yucca Mountain site, a long railspur and a moderate length of new road would have to be constructed. A long bridge would also be necessary. The terrain is such that the construction of these routes will cause minimal environmental disruption.

Cost of transportation infrastructure. This major consideration addresses the cost of constructing and upgrading the access routes to the sites. Its importance is gained from the emphasis in the qualifying condition on the local infrastructure and access routes. It is not as important as the first consideration because the protection of health and safety is more important than reducing costs.

The cost of the transportation infrastructure is considered separately from the costs of transporting waste to the site. Table 7-17 presents a comparison of costs for the construction of new road and rail access routes and the upgrading of existing networks at each site.

A favorable site for this consideration is one that needs little, if any, repair or upgrading of access routes. Other qualities of a favorable site include no requirement for Federal condemnation for rights-of-ways, a flat terrain, low costs for rights-of-way, and absence of other local anomalous features that may increase costs. A less favorable site has a poorly maintained or no transportation infrastructure; if it does exist, it is a long distance from the site, thus requiring much new construction. Other qualities of a less favorable site are a mountainous terrain, high costs for rights-of-way, the need to secure rights-of-way by Federal condemnation, and other features that could require expensive mitigation.

Cost of transportation hardware and operations. The least important consideration is the cost of developing the cask fleet and shipping the waste to the repository. This consideration is not as important as the others because transportation costs are relatively insensitive to location, and the protection of health and safety is more important than reducing costs.

The cost of transporting spent fuel to the repository sites depends to some extent on distance; that is, it costs about as much to ship waste 1,000 miles as it does 500 miles. Other factors that can influence cost, at least as determined at this stage of investigation, provide little additional guidance for discriminating among sites. A summary of transportation costs is presented in Table 7-16.

Like transportation safety, transportation cost is also affected by decisions about the configuration of the waste-management system, such as the second repository. The effect of the second repository is considered as quantitatively as possible.

A favorable site is one that is close to the sources of waste, is not subject to weather that will interfere with access to the repository, is served by existing carriers, is located in an area with emergency-response capabilities, is not located near communities that impose legal impediments to transport, and is served by rail routes that require few crew changes. A less-favorable site has characteristics that are the converse of the above factors.

Summary of comparative evaluations

The Richton site is the leading site for the major considerations that address transportation safety and the cost of transportation hardware and operations; it is the second most favorable site with respect to environmental disruption and the cost of the infrastructure. Because of the paramount importance assigned to transportation safety, the Richton site is the most favorable. The Deaf Smith site is distinguished from Richton mainly by being farther from the sources of the waste. The Hanford site is less favorable from a nationwide transportation perspective because it is the farthest from the sources of the waste. Local conditions at Hanford, however, are highly favorable in terms of safety, cost, and environmental disruption. Yucca Mountain, which is about equal in favorability to Hanford, is far from the sources of waste and would require major construction of access routes. Davis Canyon is the least favorable site for this guideline. Although it is moderately far from the sources of the waste, it is not readily accessible because the terrain in the area is very rugged. Moreover, major construction of highways and railroads is required, and it would cause significant environmental impacts.

7.3.2.2 System guideline on environment, socioeconomics, and transportation

Ranked second in importance in the preclosure system guidelines is environment, socioeconomics, and transportation. The pertinent system elements for environment, socioeconomics, and transportation (10 CFR 960.5-1(a)(2)) will, in general, consist of (1) the people who may be affected, including their lifestyles, sources of income, social and aesthetic values, and community services; (2) the air, land, water, plants, animals, and cultural resources in the areas potentially affected by such activities; (3) the transportation infrastructure; and (4) the potential mitigating measures that can be used to achieve compliance with this guideline. To provide a comparative context for understanding the evaluation of this system guideline

in Chapter 6, this section presents a brief summary of the evaluation of each site in terms of the system elements.

At Davis Canyon, the level of suspended particulates and gaseous emissions will increase during repository construction and operation. However, the concentrations of total suspended particulates (TSP) and nitrogen dioxide during all phases would be below the national ambient air quality standards (40 CFR Part 50). Construction lighting may have an effect on skyglow in the vicinity of the site. Repository construction and operation would increase the levels of noise, which may be heard in the Canyonlands National Park. It is expected that direct impacts on cultural resources during siting and construction can be minimized. Indirect impacts would not result in a loss of significant amounts of cultural information.

The site would not intrude on nearby dedicated lands. Transportation access to the Newspaper Rock State Historical Monument and the Canyonlands National Park would be temporarily disrupted. No unique aquatic or terrestrial habitat is likely to be significantly affected by the repository. The overall visual impacts of the repository would not be significant away from the immediate vicinity of the repository, except along Utah 211 and from the Davis Canyon Jeep Trail. The surface facilities would not be visible from any scenic view points or key observation points in Canyonlands National Park. A repository in Davis Canyon would, however, cause a significant adverse visual impact as viewed from the upper reaches of Davis Canyon in the park. Each of the four alternative rail corridors would create significant visual-contrast impacts from two to three key observation points in the area; none of these is inside the park.

Cumulative impacts on the Canyonlands National Park include shared traffic on Utah 211 (during site characterization), increased particulates and noise at the edge of the park, visibility of the site from Davis Canyon at the park boundary, sky brightness at night, and the potential of nearby industrial development. The impact of episodic noise intrusion on solitude in the park would be significant, but of short duration. During repository operations, all impacts mentioned above will be eliminated or reduced in the sections of the park designated for scenic, cultural, or solitude enjoyment purposes.

At Davis Canyon, available labor supplies within commuting distance of the site are expected to be insufficient to meet the requirements of the repository. The projected number of persons (workers and families) expected to in-migrate into the area during peak employment is significant. This would result in significant population increases in the rural communities of Monticello, Blanding, and Moab.

The population increase would require additional community services and facilities. The need for expanded community services and facilities could result in financial burdens to host communities because increased revenues from project and worker expenditures may not immediately be available to finance these capital expenditures. The increased demand for labor could reduce local unemployment but also cause competition and decreases in the labor available for other sectors of the economy. Advance community-development planning and financial and technical assistance can lessen the impacts on affected communities. Increased tax revenues and business activity would contribute to mitigation in the long term. Significant population

increases would also cause social changes within communities. Planning for additional protective, social, and cultural services can mitigate these changes.

Some temporary disruption in the existing vehicle-traffic flow can be expected, and some localized inconveniences experienced, during the construction of new transportation corridors and the upgrading of others. Depending on the alternative road and railroad routes selected for the repository and the time of year, some threatened and endangered species or their preferred habitats may be affected. The radiological risks of transportation appear to be small. Estimates indicate that the maximally exposed individual could receive up to 3 percent of the doses delivered by natural background radiation. It may be possible to provide new highway and rail routes that will not disrupt local cities and towns.

At the Deaf Smith site, the local areas would sustain increases in suspended particulates and nitrogen oxide emissions, particularly during site clearing and construction. Mitigation measures would limit any significant increases of suspended particulates to the immediate vicinity of the site. Preliminary modeling results indicate air quality can be maintained within regulatory standards. Short-term increases in sound levels will occur in areas around drilling sites and near truck-mounted generators during the site characterization. At the nearest residences, noise during some stages of construction could exceed EPA guidelines. Practical engineering measures can be used to prevent runoff and ground-water contamination from the salt pile at the site. Salt-handling and control measures would be used to minimize the deposition of wind-blown salt on adjacent lands.

The site is in an agricultural area that is heavily dependent on irrigation. While the repository would represent a water demand on a limited resource, the demand is less than that required to irrigate an equivalent area. Repository development will divert 5,760 acres from potential agricultural uses. The withdrawal of this land represents less than 1 percent of the total prime farmland in the county. Neither the site nor potential transportation corridors would intrude on any dedicated resource areas. No unique aquatic or terrestrial species are likely to be affected. Structures and equipment at the site during siting and construction would be visible but not visually atypical of the region. Depending on the distance, the visual intrusion will range from moderate to high.

At the Deaf Smith site, employment predictions indicate that the available labor supply within commuting distance to the site would not be sufficient to satisfy repository labor requirements, particularly during the peak employment periods. Some in-migration of workers is therefore likely. The area seems able to absorb the projected population changes without significant disruptions in housing and other community services. However, some increases in the demand for community services can be expected. Increased tax revenues and mitigation grants from the DOE will assist in providing required additional services.

There are several feasible highway and railroad access routes to the Deaf Smith site that do not irreconcilably conflict with Federally protected resource areas. These routes can be designed and constructed with available technology and will not require waste-transportation packaging standards more

stringent than existing NRC and DOT regulations, nor the development of new transportation casks. A preliminary evaluation of operations over representative highways and railroads to the Deaf Smith site indicates that waste-transportation operations can be conducted over these routes without unacceptable risk to the public or impacts on the environment. Also, adequate protection for the public and the environment can be provided during both the construction of the access routes and during operation over those routes.

For the Hanford site, no adverse environmental impacts have been identified that cannot be mitigated. The site is not within any protected resource areas, and compliance with regulatory requirements should not be a problem. No federally recognized threatened or endangered species are known to use the site as a critical habitat. There are significant native American resources on the Hanford Site, but they are far enough from the repository location so that there would be no significant adverse impacts.

Projected employment and population growth associated with the repository could be readily assimilated by the area. A technically qualified work force (except for miners) is located in the Tri-Cities and surrounding area. Roads, schools, utilities, and housing are all expected to have the ability to accept additional people in the area without stress on community services and facilities.

Access routes to the site would have no undesirable features that would require unique design or construction methods or special features of transportation system components, including the transportation packaging. Risks to public health and safety of proposed access routes would be acceptably low, since these routes are short and pass through areas without population. The environmental impacts of transportation are expected to be acceptably low, since the access routes are short and do not pass through protected resource areas. Projected risks, costs, and other impacts of waste transportation have been considered in repository siting, and transportation operations would be conducted in compliance with applicable regulation.

At the Richton site, the residual air-quality impacts are acceptable because they are below secondary standards. Clearing and construction activities would increase ambient noise levels near the site. Engineering design and distance to the nearest residences in the area will mitigate these noise levels to acceptable levels.

The construction of shafts to the underground facility would require the penetration of aquifers. Engineering safeguards to prevent threats to this water source are a recognized necessity. Existing technology is adequate to provide the needed protection.

Engineering measures can be used to prevent runoff and ground-water contamination from the salt pile at the site. Salt handling and control measures would be used to minimize the deposition of wind-blown salt. No known cultural resources will be affected by project activities.

The site would not intrude on any dedicated land or recreational areas. Any potential transportation rights-of-way that may be required through land under the National Forest System would be sited on existing or abandoned rights-of-way, thus minimizing land disruption.

No unique aquatic or terrestrial species are likely to be significantly affected. The surface facilities will be visible to some areas in the vicinity of the site. However, the emplacement is not likely to affect any existing unique features of the area.

At the Richton site, Employment predictions indicate that the available labor supply within commuting distances to the site will not be sufficient to satisfy repository labor requirements, particularly during peak employment. Some in-migration will therefore occur. Job-training programs can provide opportunities of employment for area residents, thus decreasing in-migration. The area seems capable of absorbing the projected population change without significant disruptions in housing and other community services. However, some increased demand for community services can be expected. Increased tax revenues will be received by State and local government. The town of Richton will experience impacts. This population increase would require expanded community services and facilities and may cause social changes in the town of Richton. Advanced community-development planning can lessen these impacts.

Some temporary disruption in existing vehicular traffic flow can be expected, and some localized inconvenience may be experienced during the construction of new transportation corridors and upgrading of others. The radiological risks of waste transportation appear to be small. Estimates indicate that the maximally exposed individual could receive up to 5 percent of the dose delivered by normal background radiation. Needed new highway and rail routes can be provided without disruption to local cities and towns.

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

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

Negative impacts on community services, housing supply and demand, and the finances of State and local government agencies in the affected area are not expected to be significant for repository siting, construction, operations, and decommissioning at Yucca Mountain.

The affected area, including the Las Vegas Valley, has the ability to absorb the repository-related population changes without significant disruptions of community services and without significant impacts on housing supply and demand.

Although community-specific service and housing demands could increase at rates proportional to the maximum 1-year community-population-growth rates estimated with the repository, these rates are generally within the range of those experienced historically by the urban communities and their municipal service providers. Because the unincorporated towns nearest the Yucca Mountain site have limited capability for community services, the potential population growth in these communities would generally impact county-wide service providers. These service providers are more likely to have resources for managing growth. In addition, the community-level growth rates estimated for the unincorporated towns are generally within the range of those experienced historically by Nye and Clark Counties. The work force in southern Nevada is sufficiently large to site, construct, and operate a repository at Yucca Mountain. Although an adequate total work force may be available for a repository at Yucca Mountain, the available work force with mining skills would be inadequate, and the available construction work force may also be inadequate. A repository at Yucca Mountain would increase employment and business sales in southern Nevada. Community services and government revenues are likely to increase.

For rail access to Yucca Mountain, a rail line extending approximately 100 miles from the existing mainline rail facilities at Dike Siding has been proposed. This route would be entirely on lands administered by the DOE and the U.S. Department of the Air Force and public-domain lands under the jurisdiction of the Bureau of Land Management. The terrain over which the rail line would cross is gently sloping. No tunnels and only a minor amount of excavation and fill would be required. A bridge would be required at Fortymile Wash several miles east of Yucca Mountain.

For highway access to the proposed site, a route is projected northward from U.S. Highway 95, originating approximately 0.5 mile west of the intersection of U.S. Highway 95 and Nevada State Route 373. The roadway access would be constructed on federally controlled lands that slope gently and would pose no significant engineering problems. No tunnels and only a minor amount of excavation would be required. Some minor drainage control measures and a bridge spanning Fortymile Wash would be required. The bridge would accommodate both the railroad and trucks. Between Las vegas and Mercury U.S. Highway 95 is a four-lane divided highway; it is a two-lane highway from Mercury to the access road near the intersection of U.S. Highway 95 and Nevada State Route 373. A requirement for significant upgrading of this regional highway is unlikely.

The evidence does not support a finding that any of the sites is not likely to meet the qualifying condition for environment, socioeconomic, and transportation.

7.3.3 EASE AND COST OF SITING, CONSTRUCTION, OPERATION, AND CLOSURE

7.3.3.1 Technical guidelines

The four technical guidelines in this group address the surface characteristics of the site, the characteristics of the host rock and the surrounding strata, hydrologic conditions, and tectonics. These guidelines are concerned with the ease and cost of siting, constructing, operating, and closing the repository.

7.3.3.1.1 Surface characteristics

The qualifying condition for surface characteristics is as follows:

> The site shall be located such that, considering the surface characteristics and conditions of the site and surrounding area, including surface-water systems and the terrain, the requirements specified in §960.5-1(a)(3) can be met during repository siting, construction, operation, and closure.

Major Considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-18), there are two major considerations that influence the favorability of the sites with respect to the qualifying condition. These major considerations, in order of decreasing importance, are (1) the potential for flooding the surface or underground facilities and (2) the characteristics of the terrain.

Evaluation of sites in terms of the major considerations

Potential for flooding surface or underground facilities.

This consideration is derived from the potentially adverse condition. It is important because the effects of flooding can be significant design considerations for cost and safety. The potential for, and the frequency of, flooding depend on the terrain and drainage of a site. Contributing factors are the location and likelihood of flooding from natural causes at the surface or underground facilities, the failure of man made surface-water impoundments, and the failure of engineered components of the repository. A summary of the evaluation for each site follows.

At the Davis Canyon site, a portion of the repository operations area lies within the flood plains of the 100-year and the probable maximum flood. There are no surface-water impoundments whose failure could flood the surface facilities, and there are no known surface characteristics that could cause the failure of engineered repository components. The potential for flooding would be reduced by using fill to elevate the site and constructing a lined flood-control channel.

Parts of the Deaf Smith site lie in the flood plains of the 500-year and the probable maximum flood, but no safety-related facilities would be

Table 7-18. Guideline-condition findings by major consideration—surface characteristics[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: POTENTIAL FOR FLOODING OF SURFACE OR UNDERGROUND FACILITIES					
Potentially adverse condition					
Surface characteristics that could lead to the flooding of surface or underground facilities by the occupancy and modification of flood plains, the failure of existing or planned man-made surface-water impoundments, or the failure of engineered components of the repository.	P	P	P	P	P
MAJOR CONSIDERATION 2: TERRAIN CHARACTERISTICS					
Favorable condition 1					
Generally flat terrain.	NP	P	P	P	P
Favorable condition 2					
Generally well-drained terrain.	P	P	P	P	P

[a] Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

threatened by either flood. There are no surface-water impoundments that could flood the surface facility, and surface characteristics should not lead to failures of engineered repository components. Any effects of potential flooding would be mitigated by filling during construction.

The elevation of the Hanford site protects it from the probable maximum flood of the Columbia and Yakima Rivers, including both natural flooding and dam-breached floods. A shallow probable maximum flood could occur in the southwestern portion of the site along the drainage channel of the intermittent Cold Creek. The duration of such a flood would be short, and its effects could be mitigated to preclude any danger to the workers or to the surface and subsurface facilities.

During an estimated probable maximum flood at the Richton site, the head waters of the Fox Branch river could flood the area proposed for surface facilities. There are no existing or planned man-made surface-water impoundments in the vicinity of the Dome. It is assumed that Fox Branch would be diverted and channeled around the surface facilities and that grading and fill operations would raise the elevation of the site area above the flood plain.

At the Yucca Mountain site, the exploratory shaft would be located in a wash within a flood plain that would be affected by sheet and debris flow. Parts of the candidate locations are in an area that would be affected by the 500-year and the regional maximum floods. There are no existing or planned man-made surface-water impoundments near the site that could flood the surface facilities. Some engineering measures would be required to mitigate the impacts of the probable maximum flood. The hazards of sheet and debris flow at the exploratory shafts could be mitigated by measures like channel lining or diversion.

Terrain characteristics. This consideration addresses the effects of the terrain and drainage characteristics of a site on repository construction, operation, and closure. This consideration is derived from the first and second favorable conditions. It is less important than the first consideration because the characteristics of the terrain are more closely related to the ease and cost of construction than to safety and can generally be mitigated more readily than conditions that could cause flooding.

The contributing factors for this major consideration are the terrain and drainage characteristics of the site, the potential for landslides, and soil characteristics. A summary of the evaluation for each site follows.

The area around the Davis Canyon site is characterized by steep canyons and rugged terrain. Though the terrain at the surface facilities is quite flat, the terrain through which the access roads and railroad would be constructed is rugged. Existing drainage would be rechanneled around the surface facilities during construction. Soils are likely to be well drained, with low water retention since their parent materials are mainly sandstones and siltstones.

The surface of the Deaf Smith site is nearly flat, sloping eastward less than 1 percent. Topographic features include small, internally drained lake basins (playas) and narrow stream valleys that carry surface water after

rainstorms. Soils appear to be acceptable for a large grading operation during repository construction.

The Hanford site is surrounded by an area of generally flat terrain for a radius of nearly a mile. The lack of surface-runoff features suggests the relatively coarse surficial sediments are effective in keeping the surface well drained and preventing surface-runoff features from developing north and east of the Cold Creek flood plain.

The Richton site is surrounded by generally flat terrain, with slopes of 3 to 4 percent and locally up to 10 percent. The soils are generally well drained, though small temporary ponds and marshy areas may form in the area immediately after a heavy rainfall. Soils appear to be acceptable for large grading operations during repository construction.

At Yucca Mountain, potential locations for the surface facilities are on the eastern side of the mountain. All are generally flat and covered with alluvium derived from adjacent highlands. The surface slope at these locations is less than 5 percent and in several places less than 3 percent. The exploratory-shaft facilities would be built within a wash that is partly surrounded by rugged terrain. Yucca Mountain has a well-established drainage system because of its porous alluvial soils and eastward-dipping slopes.

Summary of comparative evaluation

The most favorable site is Deaf Smith where only small parts of the site would be affected by the probable maximum flood. At Hanford, which is slightly less favorable, the probable maximum flood may reach portions of the surface facilities. Both the Deaf Smith and the Hanford sites have flat terrain that is generally well drained.

The Richton and the Yucca Mountain sites are somewhat less favorable than Deaf Smith and Hanford. At Richton site, the surface facilities would be located in the flood plain of the probable maximum flood, but the potential for flooding could be reduced by diverting the Fox Branch stream. Ponds may form after a heavy rainfall because the site is on flat terrain that is not well drained. At Yucca Mountain the exploratory-shaft facilities would be in a wash that is subject to sheet-and-debris flow and surrounded by rugged terrain. Parts of the candidate locations for the surface facilities may be within the flood plains of the 500-year and regional maximum floods. Although the surface facilities would be built on flat terrain, the site is well drained.

The Davis Canyon site is the least favorable for this guideline. The surface facilities at Davis Canyon would be within a 100-year flood plain, and the area is surrounded by steep canyons and rugged terrain. More-extensive engineering measures, such as channeling and drainage diversion, would be necessary to mitigate the impacts of a 100-year flood.

7.3.3.1.2 Rock characteristics (preclosure)

The qualifying condition for preclosure rock characteristics is as follows:

> The site shall be located such that (1) the thickness and lateral extent and the characteristics and composition of the host rock will be suitable for accommodation of the underground facility; (2) repository construction, operation, and closure will not cause undue hazard to personnel; and (3) the requirements specified in Section 960.5-1(a)(3) can be met.

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-19), there are three major considerations that influence the favorability of sites with respect to the qualifying condition. In order of decreasing importance these considerations, are (1) in situ conditions that could lead to safety hazards or difficulties during repository siting, construction, operation, and closure; (2) in situ conditions that could require engineering measures beyond reasonably available technology in the construction of the shafts and the underground facility, and (3) flexibility in selecting the location and configuration of the underground facility.

Evaluation of sites with respect to major considerations

Safety hazards and difficulties. This consideration includes in situ conditions that could lead to safety hazards or difficulties during repository siting, construction, operation, and closure. It is related to the qualifying condition through concern about safety hazards to workers and the costs and technical feasibility of mitigating difficult conditions and safety hazards. It is derived from the second favorable condition and the third, fourth, and fifth potentially adverse conditions. Because of its concern with the safety of workers, this is the most important of the considerations related to this guideline. A summary of the evaluation for each site follows.

At Davis Canyon, the mechanical properties of the salt are such that no significant safety hazards from rock instability are expected. A significant safety hazard is the potential for the presence of combustible gas. Although there is no direct evidence that such gas is present at the site, experience in salt mines at other locations suggests that it may occur. The hazards from gas can be mitigated by following safety procedures and providing adequate ventilation. The requirements for artificial rock support are expected to be relatively minor (only occasional bolting) because of the apparent massiveness of the salt and the lack of nonsalt interbeds in the host rock. Also, the presence of any carnallite in the salt should not require increased artificial support since no differences in rock strength have been observed between Paradox Basin salt and carnallite during preliminary testing. However, maintenance of underground openings may be required because of salt creep at

Table 7-19. Guideline-condition findings by major consideration—rock characteristics (preclosure)[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: SAFETY HAZARDS OR DIFFICULTIES DURING REPOSITORY SITING, CONSTRUCTION, OPERATION AND CLOSURE, INCLUDING RETRIEVAL					
Favorable condition 2					
A host rock with characteristics that would require minimal or no artificial support for underground openings to ensure safe repository construction, operation and closure.	NP	NP	NP	NP	P
Potentially adverse condition 3					
Geochemical properties that could necessitate extensive maintenance of the underground openings during repository operation and closure.	P	P	NP	P	NP
Potentially adverse condition 4					
Potential for such phenomena as thermally induced fracturing, the hydration and dehydration of mineral components, or other physical, chemical or radiation-related phenomena that could lead to safety hazards or difficulty in retrieval during repository operation.	P	P	P	P	NP
Potentially adverse condition 5					
Existing faults, shear zones, pressurized brine pockets, dissolution effects, or other stratigraphic or structural features that could compromise the safety of repository personnel because of water inflow or construction problems.	P	P	P	P	NP
MAJOR CONSIDERATION 2: ENGINEERING MEASURES BEYOND REASONABLY AVAILABLE TECHNOLOGY					
Potentially adverse condition 2					
In situ characteristics and conditions that could require engineering measures beyond reasonably available technology in the construction of the shafts and underground facility.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 3: FLEXIBILITY IN LOCATING THE REPOSITORY WITHIN THE HOST ROCK					
Favorable condition 1					
A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration and location of the underground facility.	P	NP	P	P	NP

Table 7-19. Guideline-condition findings by major consideration--rock characteristics (preclosure)[a,b] (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 3: FLEXIBILITY IN LOCATING THE REPOSITORY WITHIN THE HOST ROCK (Continued)					
Potentially adverse condition 1					
A host rock that is suitable for repository construction, operation and closure, but is so thin or laterally restricted that little flexibility is available for selecting the depth, configuration, or location of an underground facility.	NP	P	NP	NP	P

[a] Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

the candidate horizon. Salt creep will gradually reduce the size of underground openings, and, if significant, may require reexcavation to maintain minimum required dimensions. Salt creep could be a major factor if the waste needs to be retrieved, because it could cause difficulties in maintaining room stability and emplacement holes. However, available information indicates that the salt at Davis Canyon should have a relatively low rate of creep during the duration of the preclosure period.

At the Deaf Smith site, possible safety hazards are the potential for mine-roof instabilities, water inflow down the shaft from aquifers above the repository, and the presence of combustible gas. Interbeds in the salt above the underground openings may cause mine-roof instabilities. Rock falls can be prevented by adequate artificial supports. Water inflow from overlying aquifers can readily be prevented through ground-treatment and shaft-sealing techniques. Although there is no direct evidence that combustible gas is present at the site, experience in salt mines at other locations suggests that it may occur. The hazards from such gas can be mitigated by following safety procedures and providing adequate ventilation. The only artificial rock support required at the site is expected to be regular rock bolting, which will be needed to minimize mine-roof instabilities caused by interbeds in the roof. As at Davis Canyon, maintenance of underground openings may be required because of salt creep. Available information indicates that the salt at the Deaf Smith site would creep at a moderate rate during the duration of the preclosure period.

The safety hazards at the Hanford site are the potential for rock instabilities, large water inflows, high temperatures in the underground facility, and the presence of combustible gas. The high-stress conditions and high rock strength of the basalt suggest a possibility for rock bursts or other hazardous rock movements. However, preliminary evaluations indicate that such bursts are not likely to occur because of the closely jointed nature of the dense interiors, low extraction ratios, and the installation of rock-support systems. Regularly spaced rock bolting and shotcrete over wire mesh would probably be used at Hanford to support the underground excavations, but the extent of needed artificial supports is uncertain because of a lack of experience under similar conditions and a lack of understanding of the impact of thermally induced stress in the emplacement rooms. The high underground temperatures are not expected to cause a significant deterioration of support or instability of the rock. The basalt should not creep significantly, but maintenance, which is typical of deep hard-rock excavations, will probably be required. The potential for large water inflows can be reduced by probing with exploratory boreholes and mitigated through ground treatment and other methods. Combustible gas may be present as it comes out of solution from the ground water. Although the expected quantity of gas is uncertain, the hazards from the gas can be mitigated by following safety procedures and providing adequate ventilation. High temperatures (120°F) in the host rock also pose a potential hazard to workers, but this hazard can be mitigated by providing ventilation, protective clothing, and artificial cooling. There is a potential for minor difficulties in waste retrieval if the emplacement holes do not remain stable during the retrieval period.

At the Richton site, the mechanical properties of the salt are such that no significant safety hazards from rock instability are expected. A possible safety hazard is the potential presence of combustible gas. Although there is no direct evidence that gases are present, experience in salt mines at other locations indicates that it may occur. Hazards from gas can be mitigated by following safety procedures and providing adequate ventilation. On the basis of experience with artificial support in salt mines in the Gulf Coast region, the artificial support required at the Richton Dome is expected to be widely spaced rock bolting. As with the other salt sites, significant maintenance of underground openings may be required because of salt creep. However, the magnitude of creep over long time periods is highly uncertain at the Richton Dome, as it is at the other sites. Available information indicates that salt at the Richton Dome would undergo a moderate rate of preclosure creep.

At Yucca Mountain, safety hazards are limited to the potential for rock falls. The rock strength of welded tuff and in situ stresses are favorable. However, the fractured nature of the tuff could cause rock falls in underground openings. Faults encountered in the underground facility may also contribute to local instabilities because of the poor quality of rock associated with brecciated fault zones. The potential for rock falls can be mitigated through the use of appropriate artificial supports for the underground openings. On the basis of previous excavation at the Nevada Test Site, the expected artificial support requirements at Yucca Mountain are regularly spaced rock bolts with steel mesh covering the rock surface. Occasional supplemental bolting or shotcrete may be required in areas of poor-quality rock, but these requirements are minimal compared with the ground support needed in similar underground construction projects. Since the tuff does not creep, little deterioration of the rock and the artificial support is expected because of time and temperature changes. Fractures in the tuff could complicate retrieval, especially if waste is emplaced in long horizontal holes. Such difficulties could be avoided by providing liners for the emplacement holes.

Complexity of engineering measures. This consideration includes in situ characteristics and conditions that could require engineering measures beyond reasonably available technology in the construction of shafts and underground facilities. The complexity of engineering measures relates directly to the concern in the qualifying condition with technical feasibility. This consideration is derived from the second potentially adverse condition. Although the success of repository construction depends on its technical feasibility, the complexity of engineering measures is second in importance to the safety of personnel. A summary of the evaluation for each site follows.

At Davis Canyon, the construction of the shafts and underground facility is not expected to require engineering measures beyond existing technology. Shaft sinking, underground excavation, artificial support, and protection against any preemplacement safety hazards (such as gas or brine pockets) can be accomplished with technology that has been developed in the salt-mining industry.

At the Deaf Smith site, the shafts and underground facility would also be constructed with technology developed in the salt-mining industry. However, because the Ogallala aquifer lies above the repository at this site, stabilizing the ground for shaft sinking and providing effective water seals for the shaft liner would be more difficult. In addition, the presence of interbeds at the repository horizon would require additional artificial support in the underground facility.

Although the technology required to construct the underground facility at the Hanford site is reasonably available, constructing the repository shafts by blind hole drilling is at the limit of available technology. The shaft would be drilled in an environment that involves a difficult combination of depth, rock conditions, ground-water conditions, and stress conditions. Because shaft drilling in equivalent environments has not been attempted, a reliable data base is not available. Potential ground-water inflows, gases, and high rock temperatures can be managed with available technology, but the combination of conditions could require engineering measures that are more extensive than that usually required in underground construction.

At the Richton site, the shafts and the underground facility can also be constructed with technology developed in the salt-mining industry. A number of salt mines have operated in the Gulf Coast region, and the expected conditions (and the technology to handle those conditions) are relatively well known.

At Yucca Mountain, the construction of the shafts and the underground facility would not require engineering measures beyond existing technology. Construction experience at the G-tunnel on the Nevada Test Site and in other excavations in tuff, coupled with the unsaturated-tuff conditions, indicate that construction at Yucca Mountain should require proved engineering techniques.

Flexibility. Flexibility in selecting the depth, configuration, and location of the underground facility is related to the thickness and the lateral extent of the host rock--the concern of the qualifying condition. Derived from the first favorable condition and the first potentially adverse condition, this consideration is judged to be less important than worker safety and technical feasibility. A summary of the evaluation for each site follows.

At Davis Canyon, the host salt bed is expected to offer significant flexibility in locating the repository. Its thickness appears to be several times greater than necessary, and the available host rock appears to extend laterally for many kilometers. It also appears that there are no significant interbeds, impurities, or other stratigraphic or structural features within the salt bed that would limit this flexibility. However, this evaluation is based on a limited database for the site.

At the Deaf Smith site, flexibility is limited by the expected presence of interbeds in the host salt bed. Although the host salt bed is relatively

thick, the interbeds in the salt restrict the vertical flexibility for locating the repository. In contrast, there is extensive lateral flexibility because the host rock appears to extend for many kilometers. This evaluation is based on geologic information obtained from boreholes near the site.

The Hanford site appears to offer restricted vertical but significant horizontal flexibility. The thickness of other basalt flows in the area varies significantly over short distances, and the predictability of the host-rock thickness at Hanford is uncertain because of a limited data base.

The host salt at the Richton site appears to offer significant flexibility. Flexibility is greatest in the vertical direction, with the salt dome extending for thousands of meters, but there is some lateral flexibility as well. Although the shape of the dome is relatively well known from boreholes and geophysical surveys, there is a potential for undetected and unfavorable internal structures in the dome that could limit flexibility.

There appears to be significant vertical flexibility to locate a repository at Yucca Mountain, but lateral flexibility may be limited by minor faults, a shallow overburden, or site anomalies. The lateral extent of homogeneous host rock outside the primary repository area has not been established.

Summary of comparative evaluations

Since Yucca Mountain is the most favorable site for the two most important considerations, it is the most favorable site for the preclosure guideline on rock characteristics. Yucca Mountain is expected to have the fewest safety hazards, and it would require only existing construction technology and minimal artificial support and maintenance. The limited host-rock flexibility does not outweigh the favorability of the other considerations.

Davis Canyon is relatively favorable for all the major considerations, but it is less favorable than Yucca Mountain. Although there is some potential for safety hazards and retrieval difficulties, and some maintenance would be needed, Davis Canyon would require only existing construction technology and offers significant flexibility in locating the underground facility. The salt at Davis Canyon is expected to creep at a slower rate than the salt at the Deaf Smith or the Richton site.

The Deaf Smith site is as favorable or only slightly less favorable than the Davis Canyon site for the major considerations. Because of the presence of interbeds, it may be more difficult to engineer the repository and maintain underground openings and waste-retrieval capability. The favorability of the site is further reduced by the limited flexibility for locating the underground facility and the faster rate of salt creep in comparison with the other salt sites.

The Richton site is generally favorable for all considerations, but it is less favorable than Davis Canyon for host-rock flexibility and less favorable than both of the other salt sites with respect to the potential for

combustible gas. Also, the salt at Richton is expected to creep at a faster rate than the salt at Davis Canyon.

Hanford is generally less favorable than the other sites for the most important considerations (safety hazards and difficulties, engineering measures) and more favorable for the least important considerations. The potential safety hazards and the engineering measures required for construction are the key considerations that make Hanford the least favorable site for this guideline.

7.3.3.1.3 Hydrology

The qualifying condition for the hydrology guideline is as follows:

> The site shall be located such that the geohydrologic setting of the site will (1) be compatible with the activities required for repository construction, operation, and closure; (2) not compromise the intended functions of the shaft liners and seals; and (3) permit the requirements specified in 960.5-1(a)(3) to be met.

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-20), there are three major considerations that influence the favorability with respect to the qualifying condition. These major considerations, in order of decreasing importance, are (1) the complexity of required ground-water-control measures, (2) the existence of surface-water systems that could cause flooding of the repository operations area, and (3) the availability of water for repository construction, operation, and closure.

Evaluation of the sites in terms of the major considerations

Complexity of required ground-water-control measures. This consideration includes ground-water conditions that could necessitate extensive and complex ground-water-control measures in shafts and drifts during repository siting, construction, operation, and closure. It relates directly to the qualifying condition by favoring hydrologic conditions that are compatible with repository construction, operation, and closure and will not compromise shaft liners and seals. This major consideration is derived from the first favorable condition and the potentially adverse condition. The complexity of required ground-water-control measures is the most important of the three considerations for hydrology because it has the greatest effect on the ease and cost of repository construction, operation, and closure. A summary of the evaluation for each site follows:

Table 7-20. Guideline-condition findings by major consideration—hydrology[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: COMPLEXITY OF REQUIRED GROUND-WATER CONTROL MEASURES					
Favorable condition 1					
Absence of aquifers between the host rock and the land surface.	NP	NP	NP	NP	P
Potentially adverse condition					
Ground-water conditions that could require complex engineering measures that are beyond reasonably available technology for repository construction, operation and closure.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 2: EXISTENCE OF SURFACE-WATER SYSTEMS THAT COULD POTENTIALLY CAUSE FLOODING OF THE REPOSITORY					
Favorable condition 2					
Absence of surface-water systems that could potentially cause flooding of the repository.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 3: AVAILABILITY OF WATER FOR CONSTRUCTION, OPERATION AND CLOSURE					
Favorable condition 3					
Availability of the water required for repository construction, operation, and closure.	P	P	P	P	P

[a] Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is <u>not</u> present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

At the Davis Canyon site, rock units above the host rock and the host rock are generally of low permeability. Several minor aquifers with limited water-producing potential are present above the host rock. The small amounts of ground water that would be encountered during shaft sinking can be readily handled with standard engineering practice.

At the Deaf Smith site, an aquifer is present between the host rock and the ground surface. The potential for ground-water inflows during the sinking of shafts through the High Plains aquifer, the unconsolidated sediments above the repository, and the water-bearing interbeds in the host salt bed can be controlled with established technology, such as pretreatment by freezing. Little ground water is expected within the repository horizon.

At the Hanford site, a number of aquifers exist between the host rock and the ground surface. During shaft sinking, ground water would be controlled with established practices. After construction, seals associated with the shaft liner would protect the shafts and repository drifts from ground-water inflow. The construction of the repository may result in the penetration of water zones under high hydrostatic head. However, the potential for large, inadvertent water inflows can be reduced by probing with exploratory boreholes in advance of drifting to locate water zones under high hydrostatic head.

At the Richton site, several aquifers are present above the host rock and adjacent to the flanks of the dome. Control of ground water during shaft sinking through the sediments above the dome and caprock would require ground freezing because of potentially high ground-water inflows and the presence of unconsolidated sediments. Little water is expected within the dome.

At the Yucca Mountain site, there are no aquifers between the host rock and the ground surface. Because the repository would be located above the water table, no significant amounts of ground water are likely to be encountered in the shafts or underground workings.

Existence of surface-water systems that could flood the geologic repository operations area. This consideration includes ponds, lakes, streams, and manmade impoundments that could flood the underground workings during repository construction, operation, and closure, endangering the safety of workers and interrupting repository operations. It relates to the implied concern in the qualifying condition with the compatibility of surface-water systems with repository construction, operation, and closure. This consideration is derived from the second favorable condition and is considered second in importance because it is generally easier to manage the potential for surface flooding than underground ground-water inflows: standard engineering measures like dikes and berms can minimize the potential for flooding. A summary of the evaluation for each site follows.

At the Davis Canyon site, the area of the surface facilities could be inundated by the 100-year and the probable maximum flood. To reduce the risk of flooding, the site would be filled in to an elevation above the flood level, and control channels would be constructed to divert any flow around the site.

At the Deaf Smith site, minor flooding occurs within the controlled area, but there are no surface-water systems that could flood the restricted area. Although a small portion of the restricted area may intercept the flood plain of the probable maximum flood, there is considerable flexibility for locating surface facilities and shafts to avoid flooding.

At the Hanford site, the probable maximum flood of the Columbia and Yakima Rivers would not reach the repository operations area. The maximum flood of the ephemeral Upper Cold Creek could reach the area proposed for the surface facilities, but flooding would be shallow and short-lived, and it would not pose a significant hazard to surface or subsurface facilities. The 100-year flood of Cold Creek is not expected to reach the surface facilities.

The surface facilities at the Richton site would be located on high ground that is drained by Fox Branch and a tributary of Linda Creek. The present site of the surface facilities would be modified by filling in low-lying areas, constructing dikes, or diverting streams to prevent flooding of the surface and underground facilities.

At the Yucca Mountain site, each of the candidate locations for surface facilities is above the flood plain of the 100-year flood, but parts of these areas would be affected by the 500-year flood and the regional maximum flood. The proposed exploratory-shaft site in Coyote Wash may be subject to localized flooding and debris flow. However, the impacts of this infrequent, localized flooding can be mitigated by engineering measures like channel lining and drainage diversion.

Availability of water for repository construction, operation, and closure. This consideration relates to the availability of an ample source of ground or surface water for repository construction, operation, and closure. It is related to the concern in the qualifying condition about the compatibility of the geohydrologic setting with the ease and cost of construction and is derived from the third favorable condition. This consideration is third in importance because, although it affects the ease and cost of construction, it has a limited effect on the technical feasibility of construction, operation, and closure. A summary of the evaluation for each site follows.

At the Davis Canyon site, ample water for repository development is not available in the immediate vicinity of the site, but water could be purchased from the San Juan Water Conservancy District. The water supply may be taken from the Colorado River south of Potash, Utah, and piped 22 miles from the river to the repository site along the proposed railroad access route.

The availability of water at the Deaf Smith site may be limited because the High Plains aquifer could become depleted through normal irrigation use within the operating lifetime of the repository. Consequently, the underlying Dockum aquifer will be evaluated during site characterization to determine its suitability as a supplementary water supply.

At the Hanford, Richton, and Yucca Mountain sites, there is ample ground water in the immediate vicinity of the sites for repository construction,

operation, and closure. There is little doubt that this water would be available for a repository at these three sites.

Summary of comparative evaluation

The Yucca Mountain site is the most favorable site for the preclosure hydrology guideline. It is the leading site for the most important consideration: the repository would be located in the unsaturated zone, and no significant amounts of ground water are likely to be encountered in the shafts and drifts. There is also ample water available for construction, operation, and closure from a source within the controlled area. Although there is a potential for flash flooding, standard drainage-control measures would protect against such flooding. Current engineering technology is more than adequate to handle the hydrologic conditions that are likely to be encountered at Yucca Mountain.

Davis Canyon is only slightly less favorable for the most important major consideration because little difficulty is expected in controlling ground water at the site. However, there is a potential for flooding, and water for the repository would have to be piped in from the Colorado River.

At the Richton site, shafts can be sunk with standard technology, but ground freezing would be required to control ground-water inflow; therefore, the Richton site is less favorable than Davis Canyon and Yucca Mountain for the most important major consideration. Ample water is available for repository construction, operation, and closure, but engineering measures would be required to divert surface drainage.

The Deaf Smith and the Hanford sites are least favorable for this guideline. At the Deaf Smith site, ground-water conditions would make shaft sinking more difficult and would require ground freezing. There is also uncertainty about the availability of ample water for the life cycle of the repository. However, there is no potential for flooding within the restricted area. At the Hanford site, there is a potential need for ground-water-control measures that are more complex and costly than those at the other sites. There is minimal potential for flooding the surface or subsurface facilities and an ample supply of water for construction, operation, and closure. However, the potential complexity of the required ground-water-control measures is judged to reduce the overall favorability of the Hanford site in comparison with Davis Canyon and Richton.

7.3.3.1.4 Tectonics (preclosure)

The qualifying condition for preclosure tectonics is as follows:

> The site shall be located in a geologic setting in which any projected effects of expected tectonic phenomena or igneous activity on repository construction, operation, or closure will be such that the requirements specified in §960.5-1(a)(3) can be met.

Major considerations

The objective of the preclosure tectonics guideline is to ensure that a site is not likely to be affected by tectonic events of such magnitude that unreasonable or unfeasible engineering design features would be required. On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-21), two major considerations are identified that affect favorability with respect to the qualifying condition: (1) the potential for earthquake ground motion at the site and (2) the potential for faulting at the site. These major considerations are of about equal importance.

Evaluation of sites in terms of the major considerations

It is important to note that the third potentially adverse condition is not present at any of the five sites (see Table 7-19). The historical seismicity in the geologic setting was used as the basis of this evaluation because it is representative of earthquake potential for short periods of time, such as the preclosure period for the repository. Current understanding indicates that a seismic event of larger than historical magnitude is not likely (less than about 1 chance in 100) to occur during the operation and closure of the repository. This interpretation does not consider earthquakes that may be associated with design events or ground-motion estimates (the second favorable condition and the second potentially adverse condition) or evidence of active faults (the first potentially adverse condition). These are considered to be of low probability. However, as discussed below, the evaluation of ground-motion potential (first major consideration) does consider the earthquake potential of tectonic structures and faults, and data developed for the evaluation of the third potentially adverse condition.

The qualifying condition for the preclosure tectonics guideline also requires an assessment of the potential for igneous activity at each of the sites. On the basis of preliminary data, igneous activity is not expected to cause any adverse preclosure impacts at any of the sites, and therefore igneous activity is not discussed further in this section.

Potential for earthquake ground motion at the site. This consideration requires an evaluation of whether strong ground motion at the site could lead to safety hazards or difficulties during repository siting, construction, operation, and closure. It is related directly to the concern in the qualifying condition about the effects of tectonic phenomena and technical feasibility. It is derived from the favorable condition and the second and third potentially adverse conditions. This major consideration is about equal in importance to the expected impact of fault displacement. Although the likelihood of ground motion at a given site is generally higher than the likelihood of faulting, ground motion and faulting can both be significant design considerations.

Contributing factors for this major consideration include the historical earthquake record, evidence of man-induced seismicity, estimates of ground motion from historical and man-induced earthquakes, the correlation of earthquakes with tectonic structures and faults, and evaluations of the effects of ground-motion hazards on design. In addition, the evaluation of

Table 7-21. Guideline-condition findings by major consideration--tectonics (preclosure)[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: POTENTIAL FOR EARTHQUAKE GROUND MOTION AT THE REPOSITORY SITE					
Favorable condition					
The nature and rates of faulting, if any, within the geologic setting are such that the magnitude and intensity of the associated seismicity are significantly less than those generally allowable for the construction and operation of nuclear facilities.	NP	P	NP	P	NP
Potentially adverse condition 2					
Historical earthquakes or past man-induced seismicity that, if either were to recur, could produce ground motion at the site in excess of reasonable design limits.	NP	NP	NP	NP	NP
Potentially adverse condition 3					
Evidence, based on correlations of earthquakes with tectonic processes and features (e.g., faults) within the geologic setting, that the magnitude of earthquakes at the site during repository construction, operation, and closure may be larger than predicted from historical seismicity.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 2: POTENTIAL FOR FAULT DISPLACEMENT AT THE REPOSITORY SITE					
Potentially adverse condition 1					
Evidence of active faulting within the geologic setting.	P	NP	P	NP	P

ground motion depends on the evaluation of potential surface faulting in the geologic setting. The potential for ground motion generally increases as the potential for faulting near the site increases. However, the ground-motion potential from all seismogenic sources cannot be evaluated individually: it must be considered collectively to accurately evaluate the potential for ground motion and associated uncertainties. A summary of the evaluation for each site follows.

At Davis Canyon, the estimated ground motion is not significantly smaller than that generally allowable for nuclear facilities. These estimates are based on the assumption that the maximum earthquake, which has a magnitude of 6.5, could occur at Shay Graben, the closest (10 miles) significant structure in the geologic setting. Ground-motion estimates associated with these faults are moderate compared with design values for nuclear facilities. Since 1979, microearthquake monitoring has detected no seismicity at the site. However, events with a magnitude of up to about 3.0 have occurred in the Paradox Basin. Although the seismic hazard appears to be low, the record of seismicity is limited. Man-induced seismicity may be occurring at one location in the Paradox Basin, but it is not firmly established. Estimates of ground motion will remain uncertain until the faults near Shay Graben and the Needles area and the potential for man-induced seismicity at the site are fully evaluated.

At the Deaf Smith site, there appear to be no Quaternary faults in the geologic setting, and the known faults are not associated with recorded seismic activity. The site has a very low potential for induced seismicity. Predicted ground motions are significantly smaller than those generally allowable for nuclear facilities. Quaternary faulting (i.e., the Meers fault) outside the geologic setting appears to be present along the Amarillo Uplift. Study of the Meers fault to determine its tectonic characteristics and earthquake potential may influence evaluations of the portion of the Amarillo Uplift in the Texas Panhandle. This may effect estimates of ground motion at the site, although the distance to the uplift is more than 30 miles. On the basis of a qualitative understanding of present conditions, projected ground motions are well below the level that is likely to cause significant damage to underground structures.

At the Hanford site, potential ground motions are not significantly smaller than those generally allowable for nuclear facilities. However, the ground motions associated with possible Quaternary faulting in the vicinity of the Hanford site are within reasonable design limits for nuclear facilities. An earthquake record of over 100 years shows the historical seismicity of the Columbia Plateau to be low to moderate. This is consistent with data from seismic monitoring initiated in 1969. Recurrence rates for moderate earthquakes (of a magnitude greater than 6 to 6.5) appear to exceed 10,000 years. Earthquakes are not currently associated with mapped geologic structures, nor do hypocenters align in a manner suggesting that there could be unmapped buried faults in the Pasco Basin. The impact and the likelihood of potential earthquake swarms at the repository site have not been determined. Although uncertainties exist, it is expected that the effects of subsurface ground motion can be mitigated by existing engineering measures.

At the Richton site, ground motion is expected to be significantly smaller than that generally allowable for nuclear facilities. Studies to date

provide no evidence of active faulting during the Quaternary Period and no association of known faults with recorded seismic events within the geologic setting. The site is in an area of extremely low earthquake frequency, and there is little potential for induced seismicity. The nearest known earthquake epicenter is 45 miles away. On the basis of a qualitative understanding of present conditions, predicted ground motions are well below the level that could cause significant damage to underground structures. Uncertainty in estimates of ground motion is considered to be relatively low, primarily because the site is located in a region with a very low level of historical seismicity. However, there is some uncertainty about the southern extent of the New Madrid fault zone. This would likely result in more long-period motion than shaking from a maximum earthquake in the site's geologic setting.

On the basis of current knowledge, there is large uncertainty in the evaluation of potential ground motion at the Yucca Mountain site. Data on the age of the last movement, the total amount of movement during the Quaternary Period, and the extent of faulting within 1 to 5 kilometers of the site are limited, and the assessment of ground motion is preliminary. It is premature to place much confidence in estimates of ground motion until a more complete assessment can be made of the extent of faulting near the site and of the appropriate assumptions for such parameters as fault length, fault displacement, attenuation relationships, and earthquake potential. The brief historical seismic record at Yucca Mountain shows no earthquakes that have produced damaging ground motions, and current estimates of recurrence intervals for large earthquakes (greater than magnitude 7.0) in the geologic setting exceed about 25,000 years. Although estimates of ground motion for the surface and subsurface facilities are not expected to be significantly smaller than for other nuclear facilities, reasonably available technology is expected to be sufficient to accommodate the seismic design requirements. These requirements would be established during site characterization. This judgment is based on current knowledge of faults near the site. The maximum acceleration from ground motion induced by underground nuclear explosions is less than that from natural earthquakes. The reader is referred to Chapter 6 of the environmental assessment for Yucca Mountain for a description of the approach to be used in establishing the appropriate seismic design requirements.

Expected impact of fault displacement at the repository site. This consideration requires an assessment of fault-displacement potential that could lead to safety hazards or difficulties during repository siting, construction, operation, and closure. It is related directly to the concern in the qualifying condition about technical feasibility and the effects of tectonic phenomena. It is derived from the first potentially adverse condition and is equal in importance to the first major consideration. Although the likelihood of faulting at a site is generally lower than the likelihood of ground motion, the need to design for fault displacement can have a significant effect on the site's favorability. Successful construction experience where fault-displacement conditions exist is an important contributing factor to favorability. Contributing factors for this major consideration are the evidence and location of, and rates of movement on, Quaternary faults in the geologic setting. A summary of the evaluation for each site follows.

In the Paradox Basin, Quaternary faulting is suspected in the vicinity of the Davis Canyon site at both Shay Graben and the Needles fault zone. However, additional data are needed to determine whether these displacements are seismogenic or related to gravitational sliding, salt flow, or salt dissolution. These faults do not trend toward the repository operations area, and there is no known seismicity within the site boundaries. Thus, no impact is expected from fault displacement at the repository site. There is uncertainty associated with this conclusion because of the possibility that mining the repository could induce seismicity at the site.

Since no active surface faulting of Quaternary age has been recognized in the geologic setting of the Deaf Smith site, there is no expected impact from fault displacement. The geologic setting has experienced little or no tectonic activity during the Quaternary Period. The Meers fault, which appears to show evidence of recent activity, is outside the geologic setting.

Quaternary faults have been identified within the geologic setting of the Hanford Site, but they do not intersect the repository location. Active faults are not known to be present at the site. Since the site is away from areas of known or suspected surface faults and there is no significant seismicity within its boundaries, no impacts from fault displacement are expected. There is uncertainty associated with this conclusion because the potential effects of earthquake swarms on underground facilities are unknown.

Studies to date provide no geologic evidence of Quaternary faulting in the geologic setting of the Richton site. Growth faults, which are not generally associated with seismicity, may occur in the Mississippi salt basin. However, because the Mississippi salt basin is not considered to contain areas of active subsidence and is isolated from the area of the Gulf Coast that is associated with growth faults in the Wiggins Anticline, active growth faulting is not expected.

There are uncertainties in the data on the age of last movement and the total movement of faults at and near Yucca Mountain during the Quaternary Period. Since the area has been mapped and studied in sufficient detail, it is unlikely that major fault zones are undetected. New data may indicate 1 centimeter of fault displacement in the eastern Crater Flat area more recently than about 6,000 years ago. Estimated recurrence intervals for large earthquakes (magnitude 7.0 or greater) associated with surface faulting appear to be long (on the order of 25,000 years). Only minor seismicity has been detected near the site. These conditions suggest that the potential for fault displacement at the site is low during the preclosure period; thus, there are no expected impacts from fault displacement. Existing seismic design technology can accommodate small amounts of surface displacement if necessary.

Summary of comparative evaluation

The Richton site is the most favorable for the preclosure tectonics guideline. It is located in a region of extremely low ground motion and seismic hazard. Ground motion at the site is likely to be accommodated by reasonably available technology. No seismogenic faults have been identified in the geologic setting.

The Deaf Smith site is similar to the Richton site for the two major considerations, except for a slightly higher potential for ground-motion impacts from the Amarillo Uplift, which reduces its favorability. No seismogenic faults have been identified in the geologic setting, the ground-motion potential for the region is low, and ground motion at the site is likely to be accommodated with existing technologies. There is some uncertainty in the potential for ground motion, primarily because the impact of earthquakes on the Amarillo Uplift requires additional study.

The Davis Canyon and the Hanford sites are favorable with respect to the potential impacts of fault displacement. However, estimates of ground motion at both sites are uncertain because of Quaternary Period faults in the geologic setting and the potential for earthquake swarms at Hanford and man-induced seismicity at Davis Canyon. Although current estimates of ground motion for both sites are considered moderate, the seismic record qualitatively indicates that the seismic hazard for these regions is low. At Davis Canyon the closest known potential seismogenic fault is about 10 miles from the site, but this fault would not intersect the site.

At Hanford, the closest potential seismogenic faults are 6.2 to 7.4 miles from the site, but they, too, would not intersect the Hanford site.

Yucca Mountain is the least favorable site for both major considerations. A qualitative understanding of faulting near the site supports the conclusion that individual faults have long recurrence intervals (on the order of 25,000 years or more) for large earthquakes (magnitude 7.0 and greater). There are uncertainties with respect to the age of the last movement and the total amount of Quaternary movement on faults within 1 to 5 kilometers the site. Although estimates of ground motion are preliminary, it is expected that available technology could accommodate likely ground motion. Final estimates of ground motion will depend on the outcome of further seismic evaluations and the full assessment of nearby faults.

7.3.3.2 System guideline on the ease and cost of siting, construction operation, and closure

The third preclosure system guideline is ease and cost of siting, construction, operation, and closure. The pertinent elements are (1) the site characteristics that affect siting, construction, operation, and closure; (2) the engineering, materials, and services necessary to conduct these activities; (3) written agreements between the DOE and affected States and affected Indian tribes and the Federal regulations that establish the requirement for these activities; and (4) the repository personnel at the site during siting, construction, operation, or closure. It is third in importance because it does not relate directly to the health, safety, and welfare of the public or the quality to the environment. A summary of the pertinent characteristics of the host rock at each site and estimates of the engineering, materials, services, and personnel costs are presented below for the salt, basalt, and tuff sites.

Total life-cycle cost estimates* for a repository in basalt (the Hanford site), salt (the Davis Canyon, Deaf Smith, and Richton sites), and tuff (the Yucca mountain site) are shown in Table 7-22. These estimates were developed as part of the DOE's annual evaluation of the adequacy of the fee (1 mill per kilowatt-hour) paid into the Nuclear Waste Fund for disposal services and do not represent final cost estimates. More definitive estimates will be completed when more-detailed designs and site-characterization data become available. The salt cost estimate was based on design parameters that are representative of a genenic salt site. Therefore, this estimate does not take into account site-specific differences that exist at each salt site.

Table 7-22 Repository cost estimates
(billions of 1984 dollars)

Site	D&E	Construction	Operation	Decommissioning	Total
Basalt	1.5	2.3	8.3	0.2	12.3
Salt[a]	1.8	1.6	4.9	0.2	8.5
Tuff	1.5	1.1	5.8	0.1	8.5

[a]All salt sites.

The major cost components identified in Table 7-22 are defined below

- Development and evaluation (D&E): Includes costs for all activities, excluding final design and construction, that are conducted before repository operation. These activities include site characterization, conceptual and license-application design, licensing, and technology development.

- Construction: Includes costs for final design and costs for the construction of all surface facilities and a limited number of underground waste-disposal rooms and corridors.

- Operation: Includes costs for the construction of most of the underground rooms and corridors and costs for the operation of the surface and underground facilities.

- Decommissioning: Includes cost for the decontamination and decommissioning of the surface facilities.

- Total: Represents the total life-cycle cost for a geologic repository and includes the sum of all the above cost components.

*U.S. Department of Energy, Analysis of the Total System Life Cycle Cost for the Civilian Radioactive Waste Management Program, DOE/RW-0024, Washington, D.C., April 1985.

The uncertainty that has been assigned to these estimates is based on engineering judgment and is ±35 percent of the total cost of the facility. This, coupled with a 10 to 40 percent contingency already built into the estimates, reflects the accuracy of preconceptual design from which the costs were derived. The exact contingency used depends on the complexity of the design of specific repository facilities or processes.

Salt repository

Host-rock depth. The horizons of the host rock at the Davis Canyon, Deaf Smith, and Richton sites are 3,000, 2,700 and 2,100 feet below the surface, respectively. The horizon assumed for the generic salt cost estimate is 3,000 feet below the service. This is a relatively deep horizon when compared with other siting alternatives.

Rock conditions and tunnel stability. At the Davis Canyon and Richton sites, the artificial rock support required is expected to be minor (only occasional rock bolting) because of the apparent massiveness of the salt and the absence of nonsalt interbeds in the host rock. However, significant maintenance may be required for underground openings because of salt creep. Salt creep will gradually reduce the size of the underground openings, and reexcavation of the openings will be required to maintain the minimum opening dimensions.

At the Deaf Smith site, the potential for roof instability is due to the interbeds that would exist above the underground openings. Rock falls can be prevented by adequate artificial support (regular rock bolting). As with the Davis Canyon and the Richton sites, significant maintenance may be required.

The in situ rock temperatures for each of the three sites are as follows: 34-43°C (93-109°F) for Davis Canyon, 27°C (81°F) for Deaf Smith, and 50°C (122°F) for Richton site.

The rock conditions assumed for the salt cost estimate include good tunnel stability, like those of the Davis Canyon and Richton sites, and favorable in situ rock temperatures similar to the Davis Canyon site. Reexcavation is assumed to be necessary to maintain the underground openings at all salt sites and was therefore assumed for the cost estimate. These parameters were selected to be representative of a generic salt site.

Ground-water conditions. At the Davis Canyon site, one minor aquifer is present above the host rock. The small amounts of ground water (28 gallons per minute) that would be encountered during shaft sinking can be readily handled with standard engineering practices. Little water is expected at the repository horizon.

At the Richton site, several regional aquifers are present above the host rock and adjacent to the flanks of the dome. Ground-water control during shaft sinking through the above-dome sediments and caprock would require ground freezing because of potentially high ground-water inflows (1,700 gallons per minute) and unconsolidated sediments above the salt dome. Little water is expected at the repository horizon the dome.

At the Deaf Smith site, there are aquifers between the host rock and the ground surface. The control of water while sinking shafts through these aquifers and water-bearing interbeds within the evaporite section can be accomplished with established technology. Potentially high ground-water inflows (1,400 gallons per minute) and unconsolidated sediments above the repository require pretreatment by freezing to allow shaft sinking through these sediments. Little water is expected within the repository horizon.

The salt cost estimate assumed that only small amounts of water would be encountered during shaft sinking (similar to Davis Canyon) and at the repository horizon (similar to all three salt sites). These conditions were assumed to be representative of a generic salt site.

Gassy conditions. Although there is no direct evidence that toxic gas is present at any of the three salt sites, experience is salt mines at other locations suggests the possibility. The hazards from such gas can be mitigated through safety procedures and adequate ventilation. These gassy conditions have been assumed in the generic salt cost estimate.

Subsurface conditions. Although specific salt sites may have certain subsurface conditions that are less favorable than others, on balance, it was assumed that mining will be conducted in a relatively good environment. This assumption was based on the subsurface conditions discussed above for the generic salt site.

Ventilation requirements. The ventilation requirements for salt can be described as moderate in comparison with basalt and tuff. Ventilation requirements are higher than those for tuff because of the deeper repository horizon and gassy conditions, but not as high as those for basalt.

Waste-package costs. The design for the waste package is determined by subsurface conditions. The salt waste package consists of a thick-walled carbon-steel container and an internal canister assembly. The internal canister assembly segregates fuel rods into compartments for the consolidated spent-fuel design, whereas a spaceframe is used for the unconsolidated spent-fuel design. No external packing is assumed. The waste-packages assumed for the generic salt cost estimate are as follows:

Parameter	Unconsolidated spent fuel	Consolidated spent fuel
PWR/BWR ratio	1/2	12/30
Number of packages	4,600	12,200
Material	Carbon steel	Carbon steel

The total cost for the fabrication of all waste packages for a salt repository is $0.7 billion. This cost is lower than that for both tuff and basalt because salt repository emplaces significantly fewer waste packages than either tuff or basalt.

Excavation quantities. Given the waste-package requirements, the excavation requirements can be calculated. For the cost estimates used here,

it was assumed that about 22 million tons of salt will be excavated. This includes 4 million tons of salt reexcavated because of creep. The total amount excavated is higher than that assumed for basalt and tuff.

Mining method. The generic salt cost estimate assumed that a mechanized mining technique will be used to develop the underground facilities. Using this technique, mining is faster than mining by the conventional drill-and-blast technique, which is used for harder rocks like tuff and basalt.

Mining rate. The mining rate for salt can be characterized as "fast average." This rating is due to high mining productivity (tons per man-shift), which is the result of the following:

- The relative softness of the rock.
- The stability of the underground openings.
- Small quantities of water underground.
- Low temperatures.

The productivity for salt is 13.3 tons per man-shift. Salt has the highest productivity of all sites considered.

Underground-facility construction ease. The construction of the underground facilities will be easier at a repository located in salt than a repository located in basalt or tuff. This conclusion is based on the information previously presented which discussed the less difficult mining conditions associated with the salt repository.

Staffing levels and labor rates. Given the mining conditions expected at the generic salt site assumed for the cost estimate, staffing levels for the underground development can be estimated. The staffing levels (in full-time equivalents) for the emplacement period are as follows:

Surface	863
Underground	252
Total	1,115

These estimates are low when compared with other siting alternatives and result from the more favorable mining conditions expected at the salt sites.

Salt has the lowest labor rate ($28.50 per hour) of the sites considered. When combined with the low staffing levels assumed for salt, the labor cost for salt is expected to be low.

Underground facilities costs. Assuming the conditions described above, the total (construction, operation, and decommissioning) cost of the underground facilities for a salt repository is $2.2 billion. This is 26 percent of the total cost of $8.5 billion shown in Table 7-22. The remaining $6.3 billion consists of $1.8 billion for development and evaluation, $3.8 billion for surface facilities, and $0.7 for waste packages. The underground facilities cost for salt ($2.2 billion) is lower than that for the other sites.

Operation duration and backfilling. The life of a salt repository is 53 years long. It consists of a 27-year emplacement period, a 23-year caretaker

period, and a 3-year backfill period. Because salt has the shortest backfill period of all the sites considered, salt also has the shortest operating life. The short operating phase, coupled with the low labor cost, results in low operating costs for salt.

Operating cost. The operating cost for a repository in salt is $4.9 billion. This is 58 percent of the total cost of $8.5 billion and is clearly the largest portion of the total-facility cost. The remaining $3.6 billion consists of $1.8 for development and evaluation, $1.6 billion for construction, and $0.2 billion for decommissioning.

Most of the operating costs are associated with the operation of the surface facilities. Of the $4.9 billion operating cost, $2.9 billion is for the operation of the surface facilities, $1.3 billion is for underground development, and $0.7 billion is for the fabrication of the waste packages.

Total facility costs. Table 7-23 presents the total facility costs for a generic salt repository. This table summarizes the costs mentioned in this section and is consistent with the costs shown in Table 7-22.

Table 7-23. Cost estimates for a salt repository (billions of 1984 dollars)

Cost category	D&E	Construction	Operation	Decommissioning	Total
D&E	1.8	0.0	0.0	0.0	1.8
Surface	--	0.8	2.9	0.1	3.8
Underground	--	0.8	1.3	0.1	2.2
Waste packages	--	0.0	0.7	0.0	0.7
Total	1.8	1.6	4.9	0.2	8.5

The total facility cost for salt is the same as for tuff and lower than that for basalt. This is due mainly to the lower underground costs resulting from favorable subsurface conditions.

Basalt repository

Host-rock depth. The interior of the Cohassett flow has been selected as the preferred candidate horizon for the basalt repository. The horizon is approximately 3,300 feet below the surface. It is the deepest horizon of all sites considered.

Rock conditions and tunnel stability. The basalt at the Hanford site is a physically and chemically stable rock that will be little affected by repository conditions. The rock is fractured. Heat-induced and rock-matrix fracturing are expected but will be minor and will not create a safety hazard.

High stress conditions are associated with basalt. This suggests that artificial support would be required for repository construction, operation, and closure. This artificial support is not considered minimal and will consist of rock bolts and shotcrete over wire mesh. This support is needed to control instabilities in the rock caused by stress. An example of a stress-induced instability is rock bursts. However, rock bursts are expected to be mild because of the low extraction ratio planned for the repository excavation and the closely jointed nature of the dense interiors. Rock bolts will use the high strength of basalt to control rock bursts or other deformations.

Basalt should not creep significantly, and therefore, maintenance of the underground openings will not be excessive.

The rock temperature in the Cohassett flow is high (51°C, or 124°F) and is a potential hazard to the health of the personnel working underground. A ventilation system that provides a continuous, acceptable working environment must be installed at the basalt repository. The effects of temperature are not expected to cause significant deterioration of support or instability of the rock.

Ground-water conditions. Aquifers are present between the Cohassett flow and the land surface. Ground-water inflow into the repository is high and is estimated to be about 100 gallons per minute. A worst-case estimate would be as high as 3,400 gallons per minute, but this is considered unlikely. The potential for these large water inflows can be reduced by drilling exploratory boreholes before excavation to identify any zones of abnormal water production.

During shaft sinking and the construction of the underground facility, ground-water will be controlled by established practices. After construction, seals associated with the shaft liner would protect the shafts and the repository drifts from ground-water inflow.

Because the rock temperature is high, it is expected that the water temperature will also be high. There is also the potential for water to enter the repository under high pressure.

Gassy conditions. Methane gas is not indigenous to basaltic rock. However, methane could occur in the underground openings because it might be introduced with any water inflow. A way to minimize the potential for methane entering the underground facilities is to control the water inflow into the repository. Ventilation will be required to control the concentration of any methane present underground. However, because of the limited amount of gas expected underground, gassy conditions were not assumed for the basalt cost estimate.

Subsurface conditions. Mining will be conducted in a difficult environment because of the conditions discussed above.

Ventilation requirements. The ventilation requirements for basalt are higher than those for salt and tuff because of the difficult subsurface conditions described above.

Waste-package costs. The design for the waste package is determined by subsurface conditions. The basalt waste package consists of a thick-walled carbon steel container and an external packing assembly. An internal spaceframe is included for unconsolidated spent fuel. The external packing consists of a mixture of basalt and bentonite. The waste-package parameters assumed for the cost estimate are as follows:

Parameter	Unconsolidated spent fuel	Consolidated spent fuel
PWR/BWR ratio	4/9	4/9
Number of packages	1,000	38,800
Material	Carbon steel	Carbon steel

The total cost for the fabrication of all basalt waste packages is $1.1 billion. This cost is high because the basalt repository emplaces more waste-packages than any of the other sites.

Excavation quantities. Given the waste-package requirements, the excavation requirements can be calculated. For the cost estimates used here, it was assumed that about 19 million tons of basalt will be excavated. This quantity is higher than that assumed for tuff, but lower than that assumed for salt.

Mining method. The basalt design assumed that the conventional drill-and-blast excavation technique will be used to develop the underground facilities. This technique is particularly suited to the subsurface conditions found at Hanford. For example, this technique is required because basaltic rock is very hard. However, the basalt mining method is slower than mechanized mining.

Mining rate. The mining rate for basalt can be characterized as "slow average." This rating is due to a low mining productivity (tons per man-shift), which is the result of the following:

- The hardness of basaltic rock.
- The depth of the repository horizon.
- The high stress conditions.
- The presence of large quantities of water underground.
- High temperatures.
- High excavation quantities.

The productivity for basalt is 3.1 tons per man-shift. This is the lowest productivity of all sites considered.

Underground facilities construction ease. The construction of the underground facilities will be more difficult for a repository located in basalt than a repository located in tuff or salt. This conclusion is based on the information previously presented which discussed the more difficult mining conditions associated with the deeper, higher temperature, saturated zones of the basalt repository.

Staffing levels and labor rates. Given the mining conditions expected at Hanford, staffing levels for the underground development can be estimated. These estimated staffing levels for the emplacement period are as follows:

Surface	917
Underground	1,051
Total	1,968

As shown above, the difficult mining conditions result in high staffing levels. When combined with a high labor rate ($31.00 per hour), the high staffing levels lead to high labor costs for basalt.

Underground-facility costs. Assuming the conditions described above, the total (construction, operation, and decommissioning) cost of the underground facilities of a basalt repository is $6.1 billion. This is just under 50 percent of the total cost of $12.3 billion shown in Table 7-22. The remaining $6.2 billion consists of $1.5 billion for development and evaluation, $3.6 billion for surface-facilities, and $1.1 billion for waste-packages. The cost of the underground facilities ($6.1 billion) is the highest of all sites considered.

Operating duration and backfilling. The basalt repository has a longer operating life than both tuff and salt: 61 years. It consists of a 27-year emplacement period, a 23-year caretaker period, and an 11-year backfill period. This is the longest operating phase of all sites considered because basalt assumed the longest backfill period. The long operating life, coupled with the high staffing levels and high labor rates, leads to high operating costs for basalt.

Operating cost. The operating cost for a basalt repository at the Hanford site is $8.3 billion. This is 67 percent of the total cost of $12.3 billion and is clearly the largest partion of the total facility cost. The remaining $4.0 billion consists of $1.5 billion for development and evaluation, $2.3 billion for construction, and $0.2 billion for decommissioning.

Most of the operating costs are associated with underground development. Of the $8.3 billion, $4.3 billion is for underground development, $2.9 billion is the operation of the surface facilities, and $1.1 billion is for the waste packages.

Total facility costs. Table 7-24 presents the total-facility costs for the basalt repository. This table summarizes the costs mentioned in this section; the costs are consistent with the costs shown in Table 7-22.

Table 7-24. Cost estimates for a basalt repository (billions of 1984 dollars)

Cost category	D&E	Construction	Operation	Decommissioning	Total
D&E	1.5	0.0	0.0	0.0	1.5
Surface	---	0.5	2.9	0.2	3.6
Underground	---	1.8	4.3	0.0	6.1
Waste packages	---	0.0	1.1	0.0	1.1
Total	1.5	2.3	8.3	0.2	12.3

The total facility cost for basalt is the highest of all sites considered. This is due primarily to the higher underground costs resulting from the difficult subsurface conditions.

Tuff repository

Host rock depth. The proposed repository horizon is about 1,200 feet deep. This is the most shallow horizon of all sites considered.

Rock conditions and tunnel stability. The welded tuff of the Toppah Spring Member at Yucca Mountain is a physically and chemically stable rock that will be little affected by repository conditions. Currently, the rock is fractured, and any additional thermally induced fracturing will be minor.

The rock strength of welded tuff and the associated in situ stresses are favorable. The fractured nature of the tuff, however, may provide the potential for rock falls in underground openings. Faults encountered in the underground facility may also contribute to local instabilities because of the poor quality of rock associated with the fault zones. The potential for rock falls can be mitigated through the use of appropriate artificial supports for the underground openings. Previous excavation experience at the Nevada Test Site indicates that the expected artificial support requirements at Yucca Mountain are regularly spaced rock bolts, with steel mesh covering the rock surface for safety. Occasional supplemental bolting or shotcrete may be required in local areas of poor-quality rock. These requirements are considered minimal.

Little deterioration of the rock and the artificial support is expected over time and from temperature changes, since the tuff does not creep. Therefore, the rock is expected to remain in a stable condition and will not require extensive maintenance for the underground openings.

The rock temperature is favorable (27°C or 81°F) and is not expected to be a hazard to the health of the personnel working underground. The effects of temperature are not expected to significantly affect the stability of the mined openings.

Ground-water conditions. At the Yucca Mountain site, there are no aquifers between the host rock and the land surface. Because the repository would be located above the water table, no significant amounts of ground water are likely to be encountered in the shafts or the underground workings.

Gassy conditions. No significant accumulations of toxic gases are expected at the repository horizon. Therefore, gassy conditions have not been assumed for the tuff cost estimate.

Subsurface conditions. Mining will be conducted in a relatively good environment, assuming the conditions discussed above.

Ventilation requirements. The ventilation requirements for tuff are lower than those for basalt and salt. This is a result of the relatively good environment expected underground.

Waste-package costs. The design for the waste package is determined by subsurface conditions. The tuff waste package consists of a stainless-steel canister and an internal spaceframe. No external packing is assumed. The waste-package parameters assumed for the cost estimate are as follows.

Parameter	Unconsolidated spent fuel	Consolidated spent fuel
PWR/BWR ratio	3/9	6/18
Number of packages	1,400	23,100
Material	Stainless steel	Stainless steel

The total cost of fabricating all tuff waste packages is $1.1 billion. This cost is high because of the combined effect of emplacing a large number of waste packages and high material costs. The cost of the tuff waste package is higher than the cost of the salt waste package for this reason. However, the tuff waste package costs the same as the basalt waste package. This happens because, though tuff emplaces a smaller number of packages than basalt, the resulting cost savings are offset by the cost of the stainless-steel container, which is higher than the cost of the carbon-steel container for basalt.

Excavation quantities. Given the waste-package requirements, the excavation requirements can be calculated. For the cost estimates used here, it was estimated that about 17 million tons of tuff will be excavated. This is lower than that assumed for salt and basalt.

Mining method. The tuff design assumed that mechanized mining techniques will be used in conjunction with conventional techniques to develop the underground facilities. This should lead to a mining rate that is faster than that basalt (conventional mining only) but not as fast as that for salt (mechanized mining only).

Mining rate. The mining rate for tuff can be characterized as "fast average." This rating is due to a high mining productivity (tons per man-shift), which is the result of the following:

- Shallow repository horizon.
- The stability of underground openings.
- Lack of water underground.
- Lower temperatures.
- Lower excavation quantities.

The productivity for tuff is 9.1 tons per man-shift. The productivity for basalt is significantly lower because of the more difficult mining conditions that will be encountered. The productivity for salt is higher largely because salt is softer than tuff and therefore can use only totally mechanized mining techniques.

Underground facilities construction ease. The construction of the underground facilities will be easier at a repository located in tuff than a repository located in basalt, but not salt. This conclusion is based on the information previously presented which discussed the mining conditions associated with the tuff repository.

Staffing levels and labor rates. Given the mining conditions expected at the tuff site, staffing levels for the underground development can be estimated. The staffing levels for the emplacement period (in full-time equivalents) are estimated to be as follows:

Surface	846
Underground	372
Total	1,218

The staffing estimates can be characterized as low, but not the lowest of all sites considered. Tuff has the highest labor rate ($32.00 per hour) of the sites considered. However, when combined with the staffing levels assumed for tuff, the labor cost is expected to be low and fall between the labor cost expected as basalt (high) and salt (low).

Underground facility costs. Assuming the conditions described above, the total (construction, operation, decommissioning) costs of the underground facilities for a tuff repository is $2.3 billion. This is 27 percent of the total cost of $8.5 billion shown in Table 7-22. The remaining $6.2 billion consists of $1.5 billion for development and evaluation, $3.6 billion for surface facilities, and $1.1 for waste packages.

Operation duration and backfilling. The tuff repository will be in operation for 58 years. This consists of a 27-year emplacement period, a 23-caretaker period, and an 8-year backfill period. The 58-year operating phase is 3 years shorter than the basalt operating period and 5 years longer than the salt operating period. This is due to the duration of the backfill period assumed for each host rock. Because of the operating period, tuff has moderate operating costs when compared with salt and basalt.

Operating costs. The operating cost for a repository located at the Yucca Mountain site is $5.8 billion. This is 68 percent of the total cost of $8.5 billion and is clearly the largest portion of the total facility cost. The remaining $2.7 billion consists of $1.5 billion for development and evaluation, $1.1 billion for construction, and $0.1 for decommissioning.

Most of the operating costs are associated with the operation of the surface facilities. Of the $5.8 billion total operating cost, $2.8 billion is for the operation of the surface facilities, $1.9 billion is for underground development, and $1.1 billion is for the waste packages.

Total facility costs. Table 7-25 presents the total facility costs for a tuff repository. This table summarizes the costs mentioned in this section and is consistent with the costs shown in Table 7-22.

Table 7-25. Cost estimates for a tuff repository (billions of 1984 dollars)

Cost category	D&E	Construction	Operation	Decommissioning	Total
D & E	1.5	0.0	0.0	0.0	1.5
Surface	---	0.7	2.8	0.1	3.6
Underground	---	0.4	1.9	0.0	2.3
Waste packages	---	0.0	1.1	0.0	1.1
Total	1.5	1.1	5.8	0.1	8.5

The total-facility cost for tuff is the same as that salt and lower than that for basalt. This is due mainly to the lower underground costs that result from favorable subsurface conditions.

GLOSSARY AND LIST OF ACRONYMS AND ABBREVIATIONS

ablation	All processes by which snow and ice are lost from a glacier; also, the amount lost.
absorbed radiation	A measure of the amount of ionizing radiation deposited in a given mass of absorbing medium. The unit of absorbed radiation is the rad.
access corridor	Access to controlled roads, railroads, transmission for utilities, or other means.
accessible environment	The atmosphere, the land surface, surface water, oceans, and the portion of the lithosphere that are outside the controlled area.
Act	The Nuclear Waste Policy Act of 1982.
actinides	Chemical elements with atomic numbers beginning at 89 and continuing through 103.
active fault	A fault along which there is recurrent movement, which is usually indicated by small periodic displacements or seismic activity.
active dissolution front	See "dissolution front."
active institutional controls	Controls instituted by government to guard a repository against intrusion and to perform monitoring or maintenance operations.
adit	A nearly horizontal passage from the surface by which a mine is entered.
adsorption	Adherence of ions or molecules that are in solution to the surface of solids with which they are in contact.
aeromagnetic survey	A survey made of the magnetic field of the earth by the use of electronic magnetometers suspended from an aircraft.
affected area	Either the area of socioeconomic impact or the area of environmental impact.
affected Indian Tribe	Any Indian Tribe (1) within whose reservation boundaries a repository for radioactive waste is proposed to be located or (2) whose federally defined possessory or usage rights to other lands outside the reservation boundaries arising out of congressionally ratified treaties may be substantially and adversely affected by the locating of such a facility: provided that the Secretary of the Interior finds, upon the petition of the appropriate governmental officials of the Tribe, that such effects are both substantial and adverse to the Tribe.

affected State	Any State that (1) has been notified by the DOE in accordance with Section 116(a) of the Act as containing a potentially acceptable site; (2) contains a candidate site for site characterization or repository development; or (3) contains a site selected for repository development.
aging	Storage of radioactive materials, especially spent nuclear fuel, to permit the decay of short-lived radionuclides.
albite	A white or colorless triclinic mineral of the feldspar group ($NaAlSi_3O_8$). It occurs commonly in igneous and metamorphic rocks.
alkaline	Having a pH greater than 7.
alluvial fan	An outspread, gently sloping mass of alluvium deposited by a stream.
alluvial piedmont	Alluvium that lies at the base of a mountain or a mountain range.
alluvium	A general term for clay, silt, sand, gravel, or similar material that is not compacted and has been deposited in fairly recent geologic time by streams, rivers, or floods.
alpha decay	A radioactive transformation in which an alpha particle is emitted by a nuclide, thus changing one nuclide to another that has a smaller atomic number and weight.
alpha particle	A positively charged particle emitted in the radioactive decay of certain nuclides. Made up of two protons and two neutrons bound together, it is identical to the nucleus of a helium atom. It is the least penetrating of the three common types of radiation--alpha, beta, and gamma.
amorphous silica	A form of silica that lacks any ordered internal structure.
amphibole	A mineral group that includes common rock-forming minerals characterized by good prismatic cleavage.
angle of internal friction	The angle between a resultant force and the line perpendicular to the plane of friction.
anhydrite	A white to grayish or reddish mineral of anhydrous calcium sulfate, $CaSO_4$.
anoxic	A general term meaning in the absence of oxygen.
anticline	An uparched fold composed of strata that dip outward from a common ridge or axis. The core of an anticline contains stratigraphically older rocks and is convex upward.

application	The act of making a finding of compliance or noncompliance with the qualifying or disqualifying conditions specified in the siting guidelines, in accordance with the types of findings specified in Appendix III of the siting guidelines.
aquiclude	A geologic formation that will not transmit water fast enough to furnish an appreciable supply.
aquifer	A formation, a group of formations, or a part of a formation that contains sufficient saturated permeable material to yield sufficient quantities of water to wells and springs.
aquitard	A confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer; a leaky confining bed. It does not yield water to wells or springs, but may serve as a storage unit for ground water. (See also "aquiclude.")
argillaceous	A term applied to all rocks or substances composed of clay minerals or having a notable portion of clay in their composition; examples are shale and slate.
argillite	A compact rock, derived from either mudstone or shale, that has undergone a somewhat higher degree of induration than is present in mudstone or shale.
artesian	A term describing ground water confined under hydrostatic pressure. The water level in a artesian well stands above the top of the artesian water body it taps. If the water level in an artesian well stands above the land surface, the well is a flowing artesian well.
atmospheric dispersion	Atmospheric transport of particulates or gases by airflow within the atmosphere and atmospheric diffusion by random air motions.
atmospheric stability class	An index that indicates the atmosphere's ability to disperse airborne releases.
atomic energy defense activity	Any activity of the Secretary of Energy performed in whole or in part in carrying out any of the following functions: naval reactor development, weapons activities, verification and control technology, defense nuclear materials production, defense nuclear waste and materials by-products management, defense nuclear materials security and safeguards and security investigations, and defense research and development.
backfill, backfilling	The placement of materials, originally removed or new, into the excavated areas of a mine, including waste-emplacement holes, drifts, accessways, and shafts.

background radiation	Radiation that is produced by sources such as naturally occurring radioactive minerals in the earth, cosmic rays, and naturally occurring radionuclides in living organisms.
barrier	Any material or structure that prevents or substantially delays the movement of water or radionuclides.
basalt	A dark to medium dark igneous rock usually formed from lava flows and composed chiefly of calcic plagioclase and clinopyroxene in a glassy or fine-grained ground mass.
basalt flow	A solidified body of lava formed from the outpouring of molten basalt from a fissure or vent. (See "intraflow structures.")
base metal	Any of the more common or more chemically active metals (e.g., lead and copper).
basement rock	Undifferentiated rocks that underly the stratified rocks of interest in an area.
basin	A depressed area in the earth's surface with no outlet. Sediments may have accumulated in such areas.
Basin and Range province	Physiographic province in the SW U.S. characterized by a series of tilted fault blocks forming longitudinal, asymmetric ridges or mountains and broad, intervening basins.
bedding	The arrangement of rock in layers of varying thickness and character.
bedrock	Solid rock that underlies all soil, sand, clay, gravel, and loose material on the earth's surface.
benchmarking of computer codes	Code-to-code comparisons in which simulations obtained with DOE codes are compared to those obtained with other available codes of the same kind. The test cases used for benchmarking will use data representative of the actual repository setting. Benchmarking is complete when a reasonable consensus between independent code predictions is achieved.
bentonite	A clay, containing the mineral montmorillonite, that was formed over time by the alteration of volcanic ash and has variable magnesium and iron contents. Bentonite can absorb large quantities of water and expand to several times its normal volume.
beta particle	A negatively charged particle, physically identical with the electron, that is emitted by certain radionuclides.
biological half-life	The time required for an organism to eliminate half the amount of a radionuclide ingested or inhaled.

biotite	A common rock-forming mineral of the mica group. It is black in hand specimen and brown or green in thin section, and it has perfect basal cleavage.
blind-hole drilling	A technique for sinking shafts. It uses a multiple-cone bit with a diameter larger than 6 feet.
block faulting	A type of vertical faulting in which the crust is divided into structural or fault blocks of different elevations and orientations.
blooie line	A pipe or flexible tube that conducts air or other gas laden with cuttings from the collar of a borehole to a point far enough removed from the drill rig to keep air around the drill dust-free.
boiling-water reactor	A nuclear reactor that uses boiling water to generate electricity.
boomtown	A community that experiences a sudden rapid growth and expansion.
borehole	An excavation, formed by drilling or digging, that is essentially cylindrical and is used for exploratory purposes.
borehole jacking test	A test that measures in situ rock-mass deformation through the application of unidirectional pressures to the opposite sides of a borehole.
borehole log	A record of the characteristics and thickness of the different layers of rock or other material encountered in the excavation of a borehole.
borosilicate glass	A silicate glass containing at least 5 percent boric acid and used to solidify commercial or defense high-level waste.
branch corridor	A corridor that runs at an angle to the main corridors of the repository and that leads to the storage rooms.
brattice	A temporary fabric curtain from directing or restricting underground ventilation flow.
breccia	Rock consisting of sharp fragments cemented together or embedded in a fine-grained matrix.
bridge plug	A downhole tool, composed primarily of slips, plug mandrell, and rubber sealing elements that is run in and set in dense, nonfractured rock in a borehole to isolate a zone. Multiple bridge plugs may be set in a borehole to isolate numerous zones.

brine	Highly saline water containing calcium (Ca), sodium (Na), potassium (K), and chlorine (Cl) and minor amounts of other elements.
brine migration	The movement of brine through interstices in rock.
broadband sound	Sound that encompasses the audible frequencies.
buffer zone	A portion of the site that surrounds the repository and is composed of an essentially undisturbed geologic and surficial environment.
bulkhead	A stone, steel, wood, or concrete wall-like structure designed to resist earth or water pressure.
cage	The car or platform of a mine hoist used to carry men or materials.
calcine	Material heated to a temperature below its melting point to bring about loss of moisture and oxidation.
calcite	A common rock-forming mineral ($CaCO_3$) that is usually white or gray. It is the chief constituent of limestone and most marble.
caldera	A large basin-shaped volcanic depression, more or less circular.
Cambrian	The oldest of the periods of the Paleozoic Era, which lasted from 570 million to 500 million years ago.
candidate site	An area, within a geohydrologic setting, that is recommended by the Secretary of Energy under Section 112 of the Act for site characterization, approved by the President under Section 112 of the Act for characterization, or undergoing site characterization under Section 113 of the Act.
canister	A metal vessel for consolidated spent fuel or solidified high-level waste. Before emplacement in the repository, the canister will be encapsulated in a disposal container.
capable fault	A fault that has exhibited one or more of the following characteristics, as described in the NRC's 10 CFR Part 50: (a) movement at or near the ground surface at least once within the past 35,000 years or movement of a recurring nature within the past 500,000 years, (b) macroseismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault, or (c) a structural relationship to a capable fault according to characteristics a and b such that movement on one could be reasonably expected to be accompanied by movement on the other.

capillary fringe	The zone immediately above the water table in which all or some of the rock pores or fractures are filled with water that is under less than atmospheric pressure and that is continuous with the water below the water table.
caprock	Layers of insoluble mineral deposits that may be derived from the dissolution of a salt dome, "capping" the dome.
carnallite	A white, brownish, or reddish mineral, $KCl \cdot MgCl_2 \cdot 6H_2O$.
carbonate	A mineral compound characterized by a fundamental anionic structure of CO_3^{+2}. Calcite ($CaCO_3$) is an example of a carbonate.
casing	(1) A liner in a shaft or borehole to prevent entry of loose rock, gas, or liquid, or to prevent the loss of circulating liquid into porous, cavernous, or fractured ground. (2) The process of inserting casing into a borehole.
cask	See "shipping cask" and "transfer cask."
catchment area	As applied to an aquifer, the recharge area and all areas that contribute to it.
Cenozoic	The latest of the eras into which geologic time, as recorded by the stratified rocks of the earth's crust, is divided; this era is considered to have begun about 65 million years ago.
chronic intake	A continuous inhalation or ingestion exposure lasting for days or years.
cladding	A long metal tube used to contain pellets of nuclear fuel; usually made of stainless steel or Zircaloy, an alloy of steel and zirconium.
cladding hulls	The empty metal casings that remain after spent fuel is removed from them for processing.
clastic rock	Any deposit that is composed of fragments of preexisting rocks or of solid products formed during the chemical weathering of such older rocks and has been transported some distance from the place of its origin.
clay	A fine-grained natural material composed mainly of hydrous aluminum silicates. It may be a mixture of clay minerals and small amounts of nonclay materials, or it may be predominantly one clay mineral. The type of clay is determined by the predominant clay mineral (i.e., kaolin, montmorillonite, illite, halloysite, etc.).

closure	Final backfilling of the remaining open operational areas of the underground repository facility and boreholes after the termination of waste emplacement, culminating in the sealing of shafts.
coefficient of friction	An experimental constant dealing with forces when two solid bodies that are in contact slide or tend to slide on each other. The constant depends largely on the roughness of the mating surfaces.
coeval	Originating or existing over the same period of time.
cohesion	Shear strength of a rock not related to interparticle friction.
collapse fracture	Any rock structure resulting from the removal of support and consequent collapse by the force of gravity.
collar	The top or uppermost portion of a shaft. A concrete ring or slab around a shaft used to prevent water inflow and to support the headframe.
colloid	A suspension of finely divided particles in a liquid, gaseous, or solid substance. Suspended particles are not easily filtered out.
colluvium	A general term applied to the accumulation of loose incoherent soil and rock material at the base of a slope.
Columbia Plateau	A region of approximately 200,000 square kilometers (78,000 square miles) occupying a major part of eastern Washington, a portion of northeastern Oregon, and a small part of western Idaho. It is underlain by a flood basalt province consisting of approximately 375,000 cubic kilometers (90,000 cubic miles) of basalt; this is called the Columbia River Basalt Group.
commercial waste	Radioactive waste generated in private industrial and other nongovernment facilities--in particular, the spent fuel discharged from nuclear power reactors and the waste resulting from the reprocessing of spent fuel.
complex	In chemistry, any combination of cations with molecules or anions containing free pairs of electrons. An organic complex is a complex in which the cation is combined with an organic ligand. An inorganic complex is formed when the cation is combined with an inorganic ligand.
compressive strength	The maximum compressive stress that can be applied to a material under given conditions before failure occurs.
conceptual model	A physical description of a system devised to show property variations as based on field and laboratory measurements and best technical judgments.

cone penetrometer test	An in situ test that provides information necessary to calculate the load-bearing capabilities of a formation by using an instrument to measure the force required to thrust a cone downward into the soil.
confined aquifer	An underground water-bearing unit or formation with defined, relatively impermeable upper and lower boundaries. It contains confined ground water whose pressure is usually greater than atmospheric pressure throughout.
confinement	As pertains to radioactivity, the confinement of radioactive material within some specified bounds; confinement differs from containment in that there is no absolute physical barrier.
confining unit	A body of impermeable or distinctly less permeable material stratigraphically adjacent to one or more aquifers.
core hole	Any hole drilled for the purpose of obtaining cores.
constitutive model	A mathematical model of a material or a process that expresses its essential quality or nature. A constitutive model is expressed by constitutive equations that mathematically express the relationship between the quantities of interest (e.g., constitutive equations establishing a linear elastic relationship between stress and strain).
contact-handled transuranic waste	Transuranic waste, usually contained in metal drums, whose surface-radiation-dose rate (less than 0.2 rem per hour) is sufficiently low to permit direct handling. Such waste does not usually require shielding other than that provided by its container.
containment	The confinement of radioactive waste within a designated boundary.
container	The metal envelope in the waste package that provides the primary containment function of the waste package and is designed to meet the containment requirements of 10 CFR Part 60.
contamination	The presence of radioactive material on the outside surfaces of a transportation vehicle, a shipping cask, repository equipment, or a waste disposal container.
continuous mining machine	A machine equipped with a rotating cutting head with picklike bits for cutting into rock and for dropping the cuttings into a collection device for loading into cars or conveyors.

controlled area	A surface location, to be marked by suitable monuments, extending horizontally no more than 5 kilometers in any direction from the outer boundary of the underground facility, and the underlying subsurface, which area has been committed to use as a geologic repository and from which incompatible activities would be prohibited before and after permanent closure.
conventional shaft-sinking methods	Methods employing drilling, blasting, and mucking procedures in shaft construction.
cooling (spent fuel)	Storage of fuel elements after discharge from reactors, usually under water, to allow for the decay of short-lived radionuclides and hence the decrease of radioactivity and heat emission to acceptable levels. Synonymous with aging.
core (geologic)	A cylindrical section of rock, usually 5 to 10 centimeters in diameter and up to several meters in length, taken as a sample of the interval penetrated by the drill.
craton	A generally large part of the earth's crust that has attained stability and is relatively immobile.
creep	Slow deformation (alteration of form) that results from long application of a stress.
creep closure	Closure of underground openings, especially openings in salt, by plastic flow of the surrounding rock under lithostatic pressure.
cristobalite	A mineral, SiO_2, that is a high-temperature form of quartz and tridymite, and occurs as white octahedrons in acidic volcanic rocks.
critical path	Environmental exposure pathway that dominates the transport of material, from the source of emission to human receptors.
criticality	The condition of supporting a nuclear chain reaction. It occurs when the number of neutrons present in one generation cycle equals the number generated in the previous cycle.
crowned roads	Roads which are slightly elevated at center to facilitate drainage.
cumulative impact	Projected impact of a proposed facility in combination with other existing and proposed facilities and actions.
cryptocrystalline	A texture of rock consisting of crystals that are too small to be recognized and distinguished under an ordinary microscope.

crystalline	Of or pertaining to the nature of a crystal (i.e., having a regular molecular structure).
crystalline rock	An inexact but convenient term designating igneous or metamorphic rock, as opposed to sedimentary rock.
cumulative impact	Projected impact of a proposed facility in combination with other existing and proposed facilities and actions.
cumulative releases of radionuclides	The total number of curies of radioactivity entering the accessible environment in any 10,000-year period, normalized on the basis of radiotoxicity in accordance with 40 CFR Part 191. The peak cumulative release of radionuclides refers to the 10,000-year period during which any such release attains its maximum predicted value.
curie	A unit of radioactivity defined as the amount of a radioactive material that has an activity of 3.7×10^{10} disintegrations per second.
Darcian flow	Flow of fluids that is described by a numerical formulation of Darcy's law.
darcy	A unit of measurement of permeability equivalent to the passage of 1 cubic centimeter of fluid, flowing in 1 second under 1 atmosphere of pressure through a porous medium with a cross-sectional area of 1 square centimeter and a length of 1 centimeter.
dBA	A sound level in decibels measured with the A-weighting network of a sound-level meter. The A-weighting network adjusts the measurement to correspond with the frequency response of the human ear.
debris flow (geologic)	A moving mass of rock fragments, soil, and mud, with more than half the particles being larger than sand size.
decay, radioactive	(1) The process whereby radioactive materials undergo a change from one isotope, element, or state to another, releasing radiation in the process. This action ultimately results in a decrease in the number of radioactive nuclei present in the sample. (2) The spontaneous transformation of one nuclide into a different nuclide or into a different isotope of the same nuclide.
decay chain	The sequence of radioactive disintegrations in succession from one nuclide to another until a stable daughter product is reached.
decibel	A unit of measure, on a logarithmic scale, of the ratio of particular sound pressure to a standard reference pressure squared. The reference pressure is 20 micropascals.

decollement	Detachment structure of strata due to deformation, resulting in independent styles of deformation in the rocks above and below.
decommissioning	The permanent removal from service of surface facilities and components necessary only for preclosure operations, after repository closure, in accordance with regulatory requirements and environmental policies.
decontamination	The removal of unwanted material (especially radioactive material) from the surface of, or from within, another material.
decrepitation	The shattering of a rock mass or rock sample caused by the buildup of excessive pressures in contained fluids as a result of heating, or the action of differential thermal expansion or contraction of its heated grains.
defense waste	Radioactive waste derived from the manufacturing of nuclear weapons and the operation of naval reactors.
density log	A gamma-gamma log used to indicate the varying bulk densities of rocks penetrated in drilling by recording the amount of back-scattering of gamma rays.
denudation	The sum of the processes that result in the wearing away or the progressive lowering of the earth's surface by various natural agents, including weather, erosion, mass wasting, and transportation.
deposition	The laying down of rock-forming material by any natural agent (e.g., the mechanical settling of sediment from suspension in water).
design bases	Information that establishes boundaries for design by specifying the functions to be performed by the structure, system, or component of a facility and the values or ranges of values for controlling parameters.
design-basis event	A credible accident or natural phenomenon (e.g., earthquakes or flood) that is used to establish design bases because its consequences are the most severe of all those postulated for other credible accidents or phenomena.
design life	The period of time for which a structure, system, or component is designed to perform its intended function. The design life of the repository ends when the repository is of no further operational use, waste retrieval is no longer a concern, and closure and decommissioning begin.
detritus	Loose rock or mineral material removed directly by mechanical means or deposited at another site.

deviatoric stress	In the engineering discipline of rock mechanics, the difference between the major principal stress and the minor principal stress.
devitrification	The process by which glassy substances lose their vitreous nature and become crystalline.
diagenesis	All the changes undergone by a sediment after its initial deposition, exclusive of weathering and metamorphism, or the recombination or rearrangement of a mineral into a new mineral. Also known as diagenetic alteration.
diapir	A geologic flow structure, either a dome or an anticline, in which overlying rocks have been ruptured by the flow upward of a plastic core material such as salt.
diapirism	The process by which a diapir is produced.
diastrophism	A general term for all movement of the crust produced by earth forces, including the formation of continents and ocean basins, plateaus and mountains, folds of strata, and faults.
diffraction (of sound)	The process by which the direction of a sound wave front is changed in direction by an obstacle or other nonhomogeneity in a medium.
diffusion	A solute-spreading phenomenon important only at low ground-water velocities.
dike (geologic)	A tabular body of igneous rock that cuts across the structure of adjacent rocks or cuts massive rocks.
dip	The angle at which a bed, stratum, vein, or any planar feature of rock is inclined from the horizontal. The dip is measured perpendicular to the strike of the planar feature. (See "strike.")
dip-slip fault	A fault in which the earth's displacement is parallel to the dip of the fault, and there is no horizontal component of movement parallel to the strike.
direct work force	People hired for jobs at the repository.
discharge point (or area)	In ground-water hydraulics, the point (or area) where water comes out of an aquifer onto the surface.
discontinuity (seismologic)	A surface at which seismic-wave velocities abruptly change; a boundary between the seismic layers of the earth.
dispersion	The solute-spreading or dilution phenomena caused by mechanical mixing during ground-water movement and molecular diffusion.

disposal	The emplacement in a repository of high-level radioactive waste, spent nuclear fuel, or other highly radioactive material with no foreseeable intent of recovery, whether or not such emplacement permits the recovery of such waste, and the isolation of such waste from the accessible environment.
disposal system	See "repository system."
disqualifying condition	A condition that, if present at a site, would eliminate that site from further consideration.
disruptive event	Any action that could breach a barrier.
dissolution	A process of chemical weathering by which minerals and rocks are dissolved in water.
dissolution front	An underground zone in which rocks or minerals are being dissolved in a fluid (more specifically, in ground water).
distribution coefficient (K_d)	The ratio of the concentration of a solute sorbed by ion-exchange substances (e.g., earth materials, particularly clays) to the concentration of the solute remaining in solution. A large distribution coefficient implies that the substance is readily sorbed and is redissolved slowly. The concentration of a material in the solid phase (i.e., rock or sediment) (moles per gram) divided by the concentration of material in the aqueous phase (moles per liter).
disturbed zone	That portion of the controlled area, excluding shafts, whose physical or chemical properties are predicted to change as a result of underground facility construction or heat generated by the emplaced radioactive waste such that the resultant change of properties could have a significant effect on the performance of a geologic repository.
dolomite	A sedimentary rock consisting mostly of the mineral magnesium calcium carbonate, $CaMg(CO_3)_2$. It is commonly found with, and is usually formed from, limestone.
dome (general)	A dome-shaped landform or rock mass; a large igneous intrusion whose surface is convex upward with sides sloping away at low but gradually increasing angles; an uplift or an anticlinal structure, either circular or elliptical, in which the rock dips gently away in all directions.
dome (salt)	A diapiric or piercement structure with a central plug that has risen through the enclosing sediments from a deep mother bed of salt.

dome growth	A term used to describe the process of salt-dome development.
dose commitment	The integrated dose that results from an intake of radioactive material when the dose is evaluated from the beginning of the intake to a later time; also used for the long-term integrated dose to which people are considered committed because radioactive material has been released to the environment.
dose equivalent (radiation)	A concept used to describe the effectiveness of a given unit of absorbed radiation dose. The unit of dose equivalent is the rem.
dose limit	The limit established by the Environmental Protection Agency or the Nuclear Regulatory Commission for the exposure of people to radiation.
dose rate	The radiation dose received per unit of time.
dosimetry	The measurement and evaluation of absorbed radiation dose or dose equivalent.
downfaulted	Rocks on the downthrown side of a fault.
downgradient	Movement of ground water from an area of higher hydraulic pressure to one of lower pressure.
downwarping	Subsidence of the earth's crust.
drag fold	A minor fold, usually one of a series, formed in an incompetent bed lying between more-competent beds, produced by movement of the competent beds in opposite directions relative to one another.
drift	In mining, a horizontal opening excavated underground. In geology, a general term for all rock material transported either by a glacier or by proglacial meltwater.
drill-and-blast mining	A method of mining in which small-diameter holes (less than 1 foot) are drilled into the rock and then loaded with explosives. The blast from the explosives breaks the rock from the face of a structure so that rock can be removed. The underground opening is expanded by repeated drilling and blasting.
drill and test	Hydrologic testing of selected rock intervals when each interval is first penetrated by a borehole. This testing takes place before a borehole is completed to its total depth.

drill hole	A cylindrical hole made by drilling, especially one made by cable tool rigs or one made to explore for valuable minerals or to obtain geologic information. Synonymous with borehole.
drill-stem test	A test of the productive capacity of a well when it is still full of drilling mud.
ductility	A property of a solid material that undergoes more or less plastic deformation before it ruptures.
earthquake	A sudden motion or trembling in the earth caused by the release of slowly accumulated strain.
ecosystem	An ecologic system composed of organisms and their environment.
ecotone	An ecological community of mixed vegetation formed by the overlapping of adjoining ecologic communities.
effective porosity	The amount of interconnected pore space and fracture openings available for the transmission of fluids, expressed as the ratio of the volume of interconnected pores and openings to the volume of rock.
Eh	The oxidation potential of a solution.
elastic modulus (modulus of elasticity)	A constant expressing the ratio of the unit stress or strain to the unit deformation of a material when a stress or strain is exerted on the material.
electrical resistivity	The electrical resistance per unit length of a unit cross-sectional area of a material.
emplacement	The act of emplacing radioactive waste, encapsulated in disposal containers, into a prepared hole.
employment multiplier	A figure based on the estimated ratio of the sum of indirect and direct project employment to direct project employment. It is multiplied by the expected project employment to give total direct and indirect employment.
endangered species	Any plant or animal species protected under Public Law 93-205 that is in danger of extinction throughout all or a significant portion of its range (other than species of insects determined to be pests).
engineered-barrier system	The manmade components of a disposal system designed to prevent the release of radionuclides from the underground facility or into the geohydrologic setting. It includes the radioactive waste form, radioactive-waste containers, material placed over and around such containers, any other components of the waste package, and barriers used to seal penetrations in and into the underground facility.

environmental assessment	The document required by Section 112(b)(1)(E) of the Nuclear Waste Policy Act of 1982.
environmental impact statement	The document required by Section 114 of the Nuclear Waste Policy Act of 1982.
eolian	Pertaining to the wind; especially said of sediment deposition by the wind, of structures like wind-formed ripple marks, or of erosion accomplished by the wind.
ephemeral drainage	A stream or portion of a stream that flows briefly in direct response to precipitation in the immediate vicinity and is dry during some or most of the year. Its channel is at all times above the water table.
epicenter (of an earthquake)	The point on the earth's surface directly above the exact subsurface location of an earthquake.
erg	A unit of energy or work equal to the work done by a force of 1 dyne acting over a distance of 1 centimeter.
erosion	The wearing-away of soil and rock by weathering, mass wasting, and the action of streams, glaciers, waves, wind, and underground water.
escarpment	A long, more or less continuous cliff or relatively steep slope that was produced by erosion or faulting and faces in one general direction, breaking the continuity of the land by separating two level or gently sloping surfaces.
evaluation	The act of carefully examining the characteristics of a site in relation to the requirements of the qualifying or disqualifying conditions specified in the siting guidelines. Evaluation includes the consideration of favorable and potentially adverse conditions.
evaporite	A sedimentary rock composed primarily of minerals from a solution that became concentrated by evaporation, especially salts deposited from a restricted or enclosed body of seawater or from the water of a salt lake.
exclusion area	The area surrounding a nuclear facility in which the licensee has the authority to control all activities, including the exclusion or removal of personnel and property from the area.
expected	Assumed to be probable or certain on the basis of existing evidence and in the absence of significant evidence to the contrary.

expected repository performance	The manner in which the repository is predicted to function, considering those conditions, processes, and events that are likely to prevail or may occur during the time period of interest.
exploratory shafts	Excavations into the host rock to the depth of the repository. The shafts will be large enough to allow people and test equipment to be transported from the surface to the underground excavations.
extensometer	An instrument used to measure strain.
extraction ratio	The ratio of the amount of rock removed to the total amount of rock available in a given area.
extrusive	Igneous rock that has been erupted onto the surface of the earth.
facies	The aspect, appearance, and characteristics of a rock unit, usually reflecting the conditions of its origin, especially as differentiating the rock unit from adjacent or associated units.
fallout (radioactive)	Fission and activation products produced by the above-ground detonation of a nuclear device.
far field	The portion of the geologic setting that lies beyond the near field.
fault	A fracture or zone of fractures along which there has been displacement of the sides relative to one another, parallel to the fracture or zone of fractures.
fault block	A structural unit of the earth's crust that is formed by faulting and is bounded completely or in part by faults. This structure behaves essentially as a unit during tectonic activity.
fault escarpment	See "fault scarp."
fault plane	The plane along which faulting has taken place.
fault scarp	The cliff or escarpment formed by a fault that reaches the earth's surface.
fault system	A system consisting of two or more fault sets that were formed at the same time.
faulting	The process of fracturing or displacement that produces faults.
favorable condition	A condition that, though not necessary to qualify a site, is presumed, if present, to enhance confidence that the qualifying condition of a particular siting guideline can be met.

feldspar	A group of abundant rock-forming minerals of the general formula $MAl(Al,Si)_3O_8$, where M is potassium, sodium, calcium, barium, rubidium, strontium, or iron. Feldspars are the most widespread of any mineral group and constitute 60 percent of the earth's crust.
feldspathic	Containing feldspar as a principal constituent.
ferromagnesian	Containing iron and magnesium.
finding	A conclusion that is reached after evaluation.
finite-element computer code	A computer code that uses the finite-element method. The finite-element method is a method of numerical analysis that divides a region of interest into discreet elements and represents the behavior of the elements with a set of simultaneous equations. Solution of the set of equations yields the behavior at discreet points within the region of interest.
fission (nuclear)	The division of the atomic nuclei into nuclides of lower mass, accompanied by the emission of gamma rays, neutrons, and significant energy.
fission product	A nuclide produced by the fission of a heavier element.
flat-jack test	Testing apparatus used for the determination of in situ stresses or rock-mass deformability.
flooding potential	Areas susceptible to flooding by precipitation-, wind-, or earthquake-induced floods (i.e., floods resulting from dam failure, river blockage or diversion, or distantly or locally generated waves) are considered to have a flooding potential.
flood plain	As defined in 10 CFR Part 60, the lowland and relatively flat areas adjoining inland and coastal waters, including the flood-prone areas of offshore islands and, at a minimum, the area that is subject to a 1-percent or greater chance of flooding in any given year.
fluid inclusion	Brine inclusion; a small opening in a rock mass (salt) containing brine; also the brine included in such an opening. Some gases also may be present.
fluvial	Of or pertaining to rivers; growing or living in a stream or river; produced by the action of a stream or river.
flux	Rate of flow over a surface (quantity per unit area per unit time).
focal-mechanism solution	A double-couple solution obtained by using the first motion of arrival of P-waves at a particular seismic-recording station.

fold (geologic)	A curve or bend of a planar structure such as rock strata or bedding planes. A fold is usually a product of deformation.
fold belt	An essentially linear region that has been subjected to folding or deformation.
formation (geologic)	The basic rock-stratigraphic unit in the local classification of rocks. It consists of a body of rock generally characterized by some degree of internal lithologic homogeneity or distinctive features.
fracture	A general term for any break or discontinuity in a rock caused by mechanical failure resulting from stress, whether or not it causes displacement on either side large enough to be visible to the unaided eye. It may be a joint, fault, or fissure caused by geological or mechanical process and can range from microscopic to macroscopic and megascopic scales.
fracture permeability	The capacity of a fracture for transmitting a fluid; it is the measure of the relative ease of fluid flow under unequal pressure.
friction hoist	A type of mine hoist in which the hoist drum supports a cable which passes over, but is not wound around the drum. The friction of the cable on the drum is sufficient to pull the cable and the supported weight. The cable extends down both sides of the drum into the shaft, so that both ends of the cable must be weighted, either by a cage or a counterweight.
fuel assembly	An assembly of nuclear-fuel rods. Also called "fuel element."
fuel consolidation	The removal of spent-fuel rods from an assembly and repacking in a denser array to reduce the volume per metric ton of fuel.
fuel element	See "fuel assembly."
fuel rod	A long slender, cylindrical tube of stainless steel or Zircaloy containing nuclear fuel in the form of uranium oxide fuel pellets. Also called "fuel pin."
fuel reprocessing	The process whereby spent fuel is dissolved, waste materials are removed, and reusable materials are segregated for reuse.
fugitive emissions	Emissions of any pollutant, including fugitive dust, that do not pass through a stack, chimney, vent, or a functionally equivalent opening and are generated by activities necessary for the continued operation of the source.

gassy mine	Underground operation in which the content of noxious or explosive gasses has been shown to exceed levels specified in 30 CFR Part 57 by the Mine Safety and Health Administration.
gamma radiation	Electromagnetic ionizing radiation that is emitted during some types of radioactive decay processes. Gamma radiation can penetrate various thicknesses of absorbed material, depending mainly on the energy of the gamma ray and the composition of the material. Gamma radiation is mainly an external radiation hazard.
general siting guidelines	See "siting guidelines."
geochemistry	The study of the distribution and amounts of the chemical elements in minerals, ores, rocks, soils, water, and the atmosphere and the chemical interactions between these phases.
geochronology	The study of time in relationship to the history of the earth.
geodetic survey	A survey of a large land area in which account is taken of the shape and size of the earth and corrections are made for the earth's curvature.
geoengineering	The application of geologic data, principles, and techniques to the study of naturally occurring rock and soil materials or ground water for the purpose of ensuring that geologic factors affecting the location, planning, design, construction, operation, and maintenance of engineering structures and the development of ground-water resources are properly recognized and adequately interpreted, used, and presented for use in engineering practice.
geohydrologic setting	The system of hydrologic units that is located within a given geologic setting.
geohydrologic system	The geohydrologic units within a geologic setting, including any recharge, discharge, interconnections between units, and any natural or man-induced processes or events that could affect ground-water flow within or among those units.
geohydrologic unit	An aquifer, a confining unit, or a combination of aquifers and combining units that constitutes a framework for a reasonably distinct component of a geohydrologic system.
geologic formation	Any igneous, sedimentary, or metamorphic rock represented as a unit in geologic mapping.

geologic repository	A system, requiring licensing by the Nuclear Regulatory Commission, that is intended to be used, or may be used, for the disposal of radioactive waste in excavated geologic media. A geologic repository includes (1) the geologic-repository operations area and (2) the portion of the geologic setting that provides isolation of the radioactive waste and is located within the controlled area.
geologic-repository operations area	A radioactive-waste facility that is part of the geologic repository, including both surface and subsurface areas and facilities where waste-handling activities are conducted.
geologic setting	The geologic, hydrologic, and geochemical systems of the region in which a geologic-repository operations area is or may be located.
geologic system	The host rock or host-rock units and surrounding rocks that provide radionuclide containment and isolation.
geologic time scale	A system of subdividing geologic time, usually presented in the form of a chart showing the names of the various divisions of time, stratigraphy, or rock as currently understood.
geomechanics	The branch of geology that deals with the response of earth materials to deformational forces and embraces the fundamentals of structural geology.
geomorphic processes	Geologic processes that are responsible for the general configuration of the earth's surface, including the development of present landforms and their relationships to underlying structures, and processes that are responsible for the geologic changes recorded by these surface features.
geomorphology	The branch of geology that deals with the general configuration of the earth's surface; specifically, the study of the classification, description, nature, origin, and development of landforms.
geophone	See "seismometer."
geophysical	Pertaining to the properties of the earth related to its structure, composition, and development.
geophysical anomaly	An area or restricted portion of information derived from a geophysical survey that is different in appearance from the general pattern of information.

geophysical log	A graphic record of the measured or computed physical characteristics of the rock section encountered in a well, plotted as a continuous function of depth.
geophysical survey	The use of one or more geophysical techniques, such as earth current, electrical, gravity, magnetic, or seismic surveys, to gather information on subsurface geology.
geosyncline	A large, generally linear trough that deeply subsided over a long period of time and in which a thick sequence of stratified sediments accumulated.
geotechnical	Pertaining to the application of scientific methods and engineering principles to the acquisition, interpretation, and use of knowledge of the materials of the earth's crust.
geothermal gradient	The rate of increase in temperature of the earth with depth. The average geothermal gradient in the earth's crust is approximately 25°C per kilometer of depth.
geotransport	Movement of radionuclides through subsurface soils and rocks, especially the movement of radionuclides in ground water. Used in contrast to "biotransport."
gouge	The clay or clayey material in a fault zone. Also crushed rock along a fault slip.
gneiss	A foliated rock formed by regional metamorphism, in which bands of granular materials alternate with bands of minerals with elongate prismatic habit.
graben	A usually elongated depression of the earth's crust between two parallel faults.
granite	A medium- to coarse-grained intrusive igneous rock consisting primarily of feldspar and quartz.
granite wash	A drillers' term for material eroded from outcrops of granite rock and redeposited to form rock having approximately the same major mineral constituents as the original rock.
grants equal to taxes	Grants made by the Secretary of Energy to each State and unit of general local government in which a site for a repository is approved equal to the amount such State and unit of general local government, respectively, would receive were they authorized to tax site characterization activities at such site, and the development and operation of such repository, as such State and unit of general local government tax and other real property and industrial activities occurring within such State and unit of general local government.

gravity survey	Measurements of the earth's gravitational field at a series of different locations. The purpose is to associate gravitational variations with differences in the distribution or densities of rock and hence rock types.
Great Basin	A subdivision of the Basin and Range province, located in southern Nevada in a broad desert region. The Yucca Mountain site is in the Great Basin.
ground acceleration	The rate of change of velocity of the ground produced by the motion of natural phenomenon (e.g., earthquakes) or man-made events (e.g., explosions and other testings).
ground magnetic survey	A determination of the magnetic field at the surface of the earth by means of ground-based instruments.
ground motion	The displacement of the ground due to the passage of elastic waves arising from earthquakes, explosions, seismic shots, and the like.
ground water	Water that occurs beneath the water table in soils and in geologic formations that are fully saturated.
ground-water basin	An underground structure with the character of a basin with respect to the collection, retention, and outflow of water.
ground-water flux	The rate of ground-water flow per unit area of porous or fractured media, measured perpendicular to the direction of flow.
ground-water recharge rate	The rate at which water is absorbed by the ground and later added to the zone of saturation.
ground-water residence time	The time that ground water remains in an aquifer or aquifer system.
ground-water sources	Aquifers that have been or could be economically developed as sources of ground water in the foreseeable future.
ground-water travel time	The time required for a unit volume of ground water to travel between two locations. The travel time is the length of the flow path divided by the velocity, where velocity is the average ground-water flux passing through the cross-sectional area of the geologic medium through which flow occurs, perpendicular to the direction of flow, divided by the effective porosity along the flow path. If discrete segments of the flow path have different hydrologic properties, the total travel time will be the sum of the travel times for each discrete segment.
grout	A mortar or cement-and-water mixture that is used to seal the walls of boreholes and shafts.

guidelines	See "siting guidelines."
Gulf interior region of the Gulf Coastal Plain	A region in northeastern Texas, northern Louisiana, and south-central Mississippi containing several hundred salt domes. Also called the "Gulf Coastal salt-dome basin" or simply the "Gulf interior region." The Richton Dome site is located in this region.
half-life	The time it takes for one-half of the radioactive atoms initially present in a sample to decay. Each radionuclide has a characteristic but constant half-life. (See also "biological half-life.")
hanging wall	The overlying side of a fault or other structure.
halite	Rock salt, which consists of sodium chloride (NaCl).
halokinesis	In salt tectonics, a general term for the study of the structure and mechanism of emplacement of salt domes and other salt-containing structures.
Hanford Site	A DOE reservation covering nearly 600 square miles in south-central Washington. A portion of this reservation has been identified as a potentially acceptable site in basalt and is called the "Hanford site" or the "reference repository location."
head, hydraulic	See "hydraulic potential" or "hydraulic head."
headframe	The steel or timber frame at the top of a shaft that supports the sheave or pulley for the hoisting cables and serves other purposes.
heat emission	For the purpose of establishing waste-package acceptance criteria, the total amount of heat dissipated from a package of radioactive waste.
heavy metal	All uranium, plutonium, or thorium placed into a nuclear reactor.
high-efficiency particulate air (HEPA) filter	A filter capable of removing at least 99.95 percent of particulate material as small as 0.3 micron from an air stream (0.3 micron is approximately the size of the particulate material in tobacco smoke).
high-level radioactive waste	The highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; other highly radioactive material that the Nuclear Regulatory Commission, consistent with existing law, determines by rule to require permanent isolation.

High Plains aquifer	An unconfined aquifer consisting of the Ogallala Formation and the Dockum Group. It is the uppermost of the three major hydrogeologic units beneath the Southern High Plains.
highly populated area	Any incorporated place (recognized by the decennial reports of the U.S. Bureau of the Census) of 2,500 or more persons, or any census-designated place (as defined and delineated by the Bureau) of 2,500 or more persons, unless it can be demonstrated that any such place has a lower population density than the mean value for the continental United States. Counties or county equivalents, whether incorporated or not, are specifically excluded from the definition of "place" as used herein.
historical seismicity	Earthquakes that occurred during recorded history, including those reported before the existence of seismographs (preinstrumental) and those recorded by seismographs (instrumental).
Holocene	An epoch of the Quaternary Period, from the end of the Pleistocene to the present.
Hooke's law	In elastic deformation, the strain is linearly proportional to the applied stress.
horizon	(1) In geology, a given definite position or interval in the stratigraphic column. (2) In this document, a specific underground level or elevation.
host rock	The rock in which the radioactive waste will be emplaced; specifically, the geologic materials that will directly encompass and will be in close proximity to the underground repository.
hot cell	A highly shielded compartment in which highly radioactive material can be handled, generally by remote control.
hundred-year storm	A storm whose intensity is such, on a statistical basis, that it is expected to recur only once every 100 years.
hydraulic conductivity	The rate of water flow through a given cross section of rock in a unit time under a unit hydraulic gradient measured perpendicular to the direction of flow. Synonymous with the ease of ground-water movement.
hydraulic gradient	A change in the static pressure of ground water, expressed in terms of the height of water above a datum per unit of distance in a given direction.
hydraulic head	The height above sea level to which a column of water can be supported by the static pressure at that point. The total hydraulic head is the sum of elevation head, pressure head, and velocity head.

hydraulics	An engineering discipline that deals with the statics and dynamics of fluids.
hydrogeologic unit	Any soil or rock unit or subsurface zone that affects the storage or movement of ground water by its porosity or permeability.
hydrograph	A graph showing stage, flow, velocity, or other characteristics of water with respect to time.
hydrologic modeling	The process of using a mathematical representation of a hydrologic system (as embodied in a computer code) to predict the flow of ground water.
hydrologic process	Any hydrologic phenomenon that exhibits a continuous change in time, whether slow or rapid.
hydrologic properties	The properties of a rock that govern the entrance of water and the capacity to hold, transmit, and deliver water, such as porosity, effective porosity, specific retention, permeability, and the directions of maximum and minimum permeabilities.
hydrologic regime	The distribution, characteristics, and interrelationships of the aqueous components of the geologic environment.
hydrologic transport	Transport of solutes through a geologic medium caused by the movement of ground water.
hydrology	The study of global water and its properties, circulation, and distribution, from the time it falls as rain water until it is returned to the atmosphere through evapotranspiration or flows into the ocean.
hydrostatic pressure	The pressure exerted by the water at any given point in a body of water that is at rest.
hydrostratigraphic unit	A term used for a body of rock having considerable lateral extent and composing a geologic framework for a reasonably distinct hydrologic system.
hydrothermal	An adjective applied to heated or hot solutions, to the processes with which these solutions are associated, and to the rocks, ore deposits, and alteration products produced by these solutions.
hydrothermal alteration	Alteration of rocks or minerals by the reaction of heated water with preexisting solid phases.
hydrothermal reactions	The reaction of materials under aqueous conditions at elevated temperatures and pressures. A component of hydrothermal test mixtures is usually the host rock, but such mixtures may contain any or all waste package components.

hypocenter	The focus or specific point at which initial rupture occurs in an earthquake.
igneous activity	The emplacement (intrusion) of molten rock (magma) into material in the earth's crust or the expulsion (intrusion) of such material onto the earth's surface or into its atmosphere or surface water.
igneous rock	A rock that solidified from molten or partly molten material (i.e., from a magma). Igneous rock is one of the three main classes into which rocks are divided, the others being metamorphic rock and sedimentary rock.
immobilization	Treatment or emplacement of wastes to impede the movement of their radionuclides.
important to safety	The engineered structures, systems, and components essential to the prevention or mitigation of any accident that could result in a radiation dose to the whole body or an organ of 0.5 rem or more at or beyond the nearest boundary of the controlled area at any time until the completion of permanent closure.
impoundment	The process of forming a lake or pond by a dam, dike, or other barrier; also, the body of water so formed.
impulsive sound	Sound of short duration (less than 1 second).
indirect employment multiplier	Figure based on the estimated ratio of project employment to the local employment resulting from both the project and project employees with their families purchasing goods and services in the area. It is multiplied by the project employment to give indirect employment growth.
indirect work force	People hired for jobs that are available because of the repository location but not at its facilities; for example, jobs with repository suppliers, town services, or retail business.
induration	The hardening of rock material by heat, pressure, or the introduction of some cementing material.
in-migrants	Workers and their families relocating permanently or temporarily to the vicinity of the site. During construction and operation, these workers and their families are considered to be in-migrants for as long as they are present.
in-migration	Moving into a region or a community, especially as part of a large-scale and continuing movement of population.
in-migration model	The analytical or mathematical representation or quantification of in-migration.

in situ	In its natural or original position. The phrase distinguishes in-place experiments, rock properties, and the like from those conducted or measured in the laboratory.
in situ stress	The magnitude and state of ground stress in a rock mass. The inherent stress in a rock mass at depth.
in situ tests	Tests that are conducted with the subject material in its original place (i.e., at the repository site and depth).
institutional controls	Administrative controls, records, physical constraints, and combinations thereof that would limit intentional or inadvertent human access to the waste emplaced in a repository.
instrumental seismicity	Earthquakes recorded on a seismograph (an instrument designed to detect and record earthquakes).
intensity (earthquake)	A measure of the effects of an earthquake on people, on structures, and on the earth's surface at a particular location; quantified by a numerical value on the modified Mercalli scale.
interbed	A bed of one kind of rock material, typically relatively thin, occurring between or alternating with beds of another kind.
intercalated	Occurring between two rock layers or within a series of layers.
interstice	An opening or space between rock materials or soil particles.
interstitial brine	Brine distribution in very small openings throughout a salt mass.
intrusive	Of or pertaining to the emplacement of magma in preexisting rock.
inversion	An atmospheric condition where a lower layer of cool air is trapped below an upper layer of warm air so that the cooler air cannot rise. Since inversions spread air horizontally, contaminating substances cannot be widely dispersed.
ion exchange	A chemical reaction in which mobile ions from a solid are exchanged for ions of like charge in a solution.
ionizing radiation	Any radiation displacing electrons from atoms or molecules, thereby producing ions (e.g., alpha, beta, and gamma radiation).

isolation	Inhibiting the transport of radioactive material so that the amounts and concentrations of this material entering the accessible environment will be kept within prescribed limits.
isolation barrier	The earth material around the underground disposal rooms; it acts to prevent radioactivity from entering the biosphere.
isopach	A line on a map drawn through points of equal thickness of a designated unit.
isopach map	A map that shows the thickness of a geologic unit throughout a geographic area by means of isopach lines at regular intervals.
isopleth	A general term for a line on a map or chart along which all points have a numerically specified constant or equal value of any given variable, element, or quantity with respect to space or time.
isotherm	A line joining data points on a map or chart having the same temperature.
joint	A surface of fracture or parting in rock, without displacement; the surface is often a plane and may occur with parallel joints to form a joint set.
K_d	See "distribution coefficient."
kinematic analysis	The analysis of displacements and strains; it is based on geometric analysis plus a number of assumptions regarding the manner in which geometrical relationships serve to indicate displacements.
L_{dn}	Day-night equivalent sound level: 24-hour equivalent sound level with a 10-dBA penalty applied for the nighttime hours (10 p.m. to 7 a.m.).
L_{ed}	Energy-equivalent sound level: the average of the time-varying sound energy.
L_{eq}	Energy-equivalent sound level: the average of the time-varying sound energy.
lacustrine	Pertaining to, produced by, or inhabiting a lake or lakes.
leachate	A solution obtained by leaching; for example, water that has percolated through soil containing soluble substances and thus contains certain amounts of these substances in solution.

leaching	The dissolution of soluble constituents of a solid material (e.g., the waste to be emplaced in a repository) by the action of percolating water or chemicals.
leakage	Ground-water flow across or through a rock zone of low permeability.
level 1	A specific finding on a disqualifying condition as described in Appendix III of the siting guidelines. A level 1 finding means "the evidence does not support a finding that the site is disqualified."
level 2	A specific finding on a disqualifying condition as described in Appendix III of the siting guidelines. A level 2 finding means "the evidence supports a finding that the site is not disqualified on the basis of that evidence and is not likely to be disqualified."
level 3	A specific finding on a qualifying condition as described in Appendix III of the siting guidelines. A level 3 finding means "the evidence does not support a finding that the site is not likely to meet the qualifying condition."
level 4	A specific finding on a qualifying condition as described in Appendix III of the siting guidelines. A level 4 finding means "the evidence supports a finding that the site meets the qualifying condition and is likely to continue to meet the qualifying condition."
license application	An application for a license from the Nuclear Regulatory Commission to construct a repository.
licensing	The process of obtaining the permits and authorizations required to site, construct, operate, close and decommission a repository.
lignite	A brownish-black coal in which the alteration of vegetable material has proceeded farther than in peat, but not so far as subbituminous coal.
lineament	A linear topographic feature of regional extent that is believed to reflect crustal structure. Examples are fault lines, aligned volcanoes, and straight stream courses.
linear energy transfer	A measure of the energy deposited per unit of path length.
linear expansion	The change in the length of a solid due to a change in temperature. The coefficient of linear expansion is the change in a solid's unit length per 1 degree change in temperature.

lithology	The study of rocks. Also the description of a rock on the basis of such characteristics as structure, color, mineral composition, grain size, and arrangement of its component parts.
lithophysae	Hollow bubblelike structures in rocks; composed of concentric shells of finely crystalline alkali feldspar, quartz, and other materials.
lithosphere	The solid part of the earth, including any ground water contained within it.
lithostatic pressure	The confining pressure at depth in the crust of the earth from the weight of the overlying rocks.
loess	A homogeneous unstratified deposit of windblown dust composed mainly of sand and silt.
log	A record that shows the character of rock being drilled, the drilling process, the drilling tools used, mud weight and condition, personnel on duty, and any pertinent or unusual events occurring during the drilling.
logging	Recording observations, conditions, activities, or measurements.
low-level transuranic waste	See "contact-handled transuranic waste."
low-level waste	Radioactive material that is not high-level radioactive waste, spent nuclear fuel, transuranic waste, or by-product material as defined in Section 11a(2) of the Atomic Energy Act of 1954.
mafic	Said of an igneous rock composed chiefly of dark ferromagnesian minerals.
magma	Naturally occurring mobile rock material, generated within the earth and capable of extrusion and intrusion, from which igneous rocks are thought to have been derived through solidification and related processes.
magnetic survey	A survey made with a magnetometer on the ground or in the air; it reveals local variations in the intensity of the magnetic field.
magnetometer	Instrument that measures the earth's magnetic field or the magnetic field of a particular rock.
magnetotelluric method	A geophysical surveying method that measures the natural electric and magnetic fields of the earth.

magnitude	The measure of the strength of an earthquake; related to the energy released in the form of seismic waves. Magnitude is quantified by a numerical value on the Richter scale.
man-rem	The unit of population dose. It is obtained by multiplying the average dose equivalent to a given organ or tissue (measured in rem) by the number of persons in a population.
maximally exposed individual	A hypothetical person who is exposed to a release of radioactivity in such a way that he receives the maximum possible individual radiation dose or dose commitment. For instance, if the release is a puff of contaminated air, the maximally exposed individual is a person at the point of the largest ground-level concentration and stays there during the whole time the contaminated-air cloud remains above. This term is not meant to imply that there really is such a person; it is used only to indicate the maximum exposure a person could receive.
maximum credible earthquake	The strongest earthquake that, considering the earthquake history and the tectonic setting of a place, could be reasonably expected to occur during the preclosure and postclosure phases of a repository.
maximum drawdown	The greatest lowering of the water table or potentiometric surface caused by pumping (or artesian flow).
maximum individual dose	The highest radiation dose delivered to the whole body or to an organ that a person can receive from a release of radioactivity. The hypothetical person who receives this dose, the maximally exposed individual, is one whose location, activities, and habits maximize the dose.
maximum permissible concentration	The average concentration of a radionuclide in air or water to which a worker or member of the general population may be continuously exposed without exceeding regulatory limits on external or internal radiation doses.
member of the public	Any individual who is not engaged in operations involving the management, storage, and disposal of radioactive waste. A worker so engaged is a member of the public except when on duty at the geologic-repository operations area.
Mercalli intensity	A scale for measuring earthquake intensity in terms of the effects perceived by people.
mesostasis	The last-formed interstitial material of an igneous rock.
Mesozoic	An era of geologic time, from the end of the Paleozoic to the beginning of the Cenozoic, or from about 225 million to about 65 million years ago.

metamorphic rock	All rocks that were formed in the solid state in response to pronounced changes in temperature, pressure, and chemical environment--changes that take place, in general, below the surface zones of weathering and cementation.
metamorphism (geologic)	The mineralogical, chemical, and structural adjustment of solid rocks to physical and chemical conditions imposed at depth below the surface zones of weathering and cementation, which differ from the conditions under which the rocks originated.
metasedimentary	Sedimentary rocks altered by the effects of heat or pressure or both.
meteorological monitoring station	A tower containing instruments to measure wind speed, wind direction, temperature at different heights, dew point, etc.
mica	A group of minerals consisting of complex silicates with perfect basal cleavage; they split into thin elastic laminae and range from colorless to black.
microearthquake	An earthquake that is not felt or has a magnitude of less than 3 on the Richter scale. Also called "microseism."
migration	See "brine migration."
millidarcy	A unit of measurement of fluid permeability equivalent to 0.001 darcy.
millirem	1 millirem is 1/1,000 of a rem.
mined geologic disposal system	See "repository system."
mineral	A naturally occurring inorganic element or compound with an orderly internal structure and a characteristic chemical composition, crystal form, and physical properties.
mineralogy	The study of minerals. Also the formation, occurrence, properties, and composition of the minerals that make up a rock.
Miocene	An epoch of geologic time in the Tertiary Period, after the Oligocene Epoch and before the Pliocene Epoch.

mitigation	(1) Avoiding the impact altogether by not taking a certain action or parts of an action. (2) Minimizing impacts by limiting the degree or magnitude of the action and its implementation. (3) Rectifying the impact by repairing, rehabilitating, or restoring the affected environment. (4) Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action. (5) Compensating for the impact by replacing or providing substitute resources or environments.
mixing height (or depth)	The height above the surface of the earth defining a layer where vigorous vertical mixing of air occurs; this mixing layer represents the vertical extent to which pollutants can be mixed in the atmosphere.
modal analysis	The analysis of the actual mineral composition of a rock, usually expressed in weight or volume percentage. See "conceptual model," "tectonic model."
model	A conceptual description and the associated mathematical representation of a system, component, or condition. It is used to predict changes in the system, component, or condition in response to internal or external stimuli as well as changes over time and space. An example is a hydrologic model to predict ground-water travel or radionuclide transport from the waste-emplacement area to the accessible environment.
modeling, hydrologic	See "hydrologic modeling."
monitoring	Routine measuring of the quantity and type of radionuclide releases from a waste-management facility or measuring of the changes in the physical, chemical, or biological characteristics of the site and the surrounding area.
modified Mercalli scale	An earthquake-intensity scale with 12 divisions ranging from I (not felt by people) to XII (damage nearly total); commonly abbreviated MM.
modulus of deformation	A term used for materials that deform in a manner other than according to Hooke's law; also called "modulus of elasticity" (see "Hooke's law").
modulus of elasticity	See "elastic modulus."
monolithic structure	A structure formed or composed of rock material without joints or seams.
moraine	A mound, ridge, or other accumulation of unsorted, unstratified rock material left at the margins of a retreating glacier.

morphology	The study of topographic features; the form of land.
muck	Broken rock that results from mining.
mudstone	A dark-gray, fine-grained shale that decomposes into mud when exposed to the atmosphere.
multibarrier system	A system of natural and engineered barriers, operating independently or relatively independently, that acts to contain and isolate the waste.
multiwell aquifer test	A test to determine an aquifer's capacity; it involves adding or withdrawing measured quantities from more than one well and measuring the resulting changes in hydraulic head.
natural background radiation	See "background radiation."
natural barrier	The physical, mechanical, chemical, and hydrologic characteristics of the geologic environment that, individually and collectively, act to minimize or preclude radionuclide transport.
natural gamma log	A log of the natural radioactivity of the rocks traversed in a borehole obtained by measuring naturally emitted gamma rays.
natural system	A host rock suitable for repository construction and waste emplacement and the surrounding rock formations. Includes natural barriers that provide containment and isolation by limiting radionuclide transport through the geohydrologic environment to the biosphere and provides conditions that will minimize the potential for human interference in the future.
near field	The region where the natural geohydrologic system has been significantly perturbed by the excavation of the repository and the emplacement of the waste.
neutron log	A radioactivity log that measures the intensity of neutrons or gamma rays produced when rocks around a borehole are bombarded by neutrons from a synthetic source.
neutron probe	A probe used to measure the intensity of radiation for a neutron log.
Nevada Test Site	An area in Clark and Nye Counties in southern Nevada; it is dedicated to the underground testing of nuclear weapons.

noble gases	A group of gases that includes helium, neon, argon, krypton, xenon, and sometimes radon. Also known as inert gases, these gases have great stability and extremely low reaction rates.
nonconformity	An unconformity in which stratified rocks above the surface rest on unstratified, older rocks.
nonradiological risk	A risk from sources other than exposure to radiation.
normal fault	A fault in which the hanging wall appears to have moved downward relative to the footwall. The angle of the fault is usually 45 to 90 degrees.
nuclide	A species of atom with a specific mass, an atomic number, and a nuclear energy state; also referred to as an "isotope."
occupational dose	The radiation dose received by a person in a restricted area or in performing work duties involving exposure to radiation.
operational phase	The period of time from the receipt of the first waste at the site of the repository to closure and decommissioning.
orogenic	Of or pertaining to the process of mountain formation, especially by folding of the earth's crust.
outcrop	The part of a geologic formation or structure that appears at the surface of the earth.
overburden	Loose soil, sand, gravel, or other unconsolidated material that overlies bedrock.
overcoring	A process that determines stress components in a rock mass. The process consists of drilling a small-diameter borehole and inserting deformation-sensing devices. A larger hole is then drilled concentrically with the first hole, which relieves the stress in the rock cylinder. The measured deformations are related to stresses through elastic relationships.
overthrust	A low-angle thrust fault of a large scale, with displacement generally measured in kilometers.
oxidation-reduction reaction	A chemical reaction in which one or more electrons are transferred between two or more chemical constituents of the system.
package	See "waste package."

packer	A device used in drilled holes to isolate one part of a borehole from another in order to carry out studies of particular formations or parts thereof.
packer-injection tests	A series of tests whereby a liquid (usually water) or gas is injected into a sealed off or isolated portion of a borehole or well to obtain data on formation permeability, fracture flow, and the like.
paleoclimate	A climate of the geologic past.
paleoecology	The study of the relationship between ancient organisms and their environment.
paleohydrology	The study of ancient hydrologic features preserved in rock.
paleomagnetism	The study of the natural remnant magnetization of the earth to determine the intensity and direction of the earth's magnetic field in the geologic past.
paleontology	The study of life of the geologic past based on fossilized plant and animal remains.
paleosol	A buried soil of the geologic past.
Paleozoic	The era of geologic time, from the end of the Precambrian to the beginning of the Mesozoic or from about 570 million to 225 million years ago.
paludal	Pertaining to a marsh or swamp.
palynology	The study of spores, pollen, and microorganisms that occur in sediments.
panel	A collection of underground rooms connected by a common access and common ventilation corridors.
Paradox Basin	A 25,900-square-kilometer (10,000-square-mile) area in southeastern Utah and southwestern Colorado; it is underlain by bedded salt and a series of salt-core anticlines. The Davis Canyon site is in the Paradox Basin.
particulates	Finely divided particles suspended in a gaseous medium, such as dust in air.
Pasco Basin	A structural and topographic basin in the western Columbia Plateau. The Hanford Site and the reference repository location are in the Pasco Basin.
passive institutional controls	(1) Permanent markers placed at a disposal site. (2) Public records or archives. (3) Federal Government ownership or control of land use. (4) Other methods of preserving knowledge about the location, design, or contents of a disposal system.

pathway	As related to waste disposal, possible or potential routes by which wastes might reach the accessible environment.
pedology	The study of the morphology, origin, and classification of soils.
perched ground water	Unconfined ground water separated from an underlying body of ground water by an unsaturated zone. Perched ground water is supported by a perching bed whose permeability is so low that water percolating downward through it is not able to bring water in the underlying unsaturated zone above atmospheric pressure.
percolate	In hydrology, the passage of a liquid through a porous substance; e.g., the movement of water, under hydrostatic pressure developed naturally underground, through the interstices and pores of the rock or soil; i.e., the slow seepage of water through soils or porous deposits.
performance assessment	Any analysis that predicts the behavior of a system or system component under a given set of constant or transient conditions. For the repository, such an analysis identifies the events and processes that might affect the disposal system, examines their effects on its barriers, and estimates the probabilities and consequences of the events.
performance confirmation	A program of test, experiments, and analyses required by the Nuclear Regulatory Commission and conducted to evaluate the accuracy and adequacy of the information used to determine reasonable assurance that the postclosure performance objectives can be met.
performance criterion	A criterion establishing qualitative operational, safety, or environmental limits.
periglacial	Pertaining to the areas, conditions, processes, and deposits marginal to an ice sheet or glacier.
permanent closure	See "closure."
permeability	The capacity of a medium like rock, sediment, or soil to transmit ground water. Permeability depends on the size and shape of the pores in the medium and the manner in which the pores are interconnected.
Permian Basin	A region in the Central United States where, during Permian time 280 to 225 million years ago, there were many shallow seas that laid down vast beds of salt and other evaporites. The Deaf Smith site is in the Permian Basin.
permissible dose	That dose of ionizing radiation that, in light of present knowledge, carries negligible probability of causing a severe somatic injury or a genetic effect.

petrography	The branch of geology that deals with the description and systematic classification of rocks, especially igneous and metamorphic rocks and especially by the microscopic examination of thin sections.
petrology	The branch of geology that deals with the origin, occurrence, structure, and history of rocks.
pH	A measure of the acidity or alkalinity of a solution.
phenocryst	A term applied to any large, conspicuous crystal in an igneous rock.
phosphatic rock	Any rock that contains one or more phosphatic minerals, especially apatite.
photogrammetry	The science and art of obtaining reliable measurements from photographs.
physiography	The descriptive study of landforms as opposed to geomorphology, which is the interpretive study of land forms.
physiographic province	A region in which all parts are similar in geologic structure and climate and which consequently had a unified geomorphic history.
piezometer	A tube or pipe in which the elevation of water level can be determined. A piezometer must be sealed along its length, and it must be open to water flow at the bottom and to the atmosphere at the top.
piezometric surface	See "potentiometric surface."
pillar	A solid mass of rock left standing to support a mine roof.
plasticity	The property of a material that enables it to undergo permanent deformation without appreciable volume change or elastic rebound without rupture.
plate bearing test	A procedure performed in small tunnels or adits to measure the deformation characteristics of a rock mass.
platform	A general term for any level or nearly level surface under water.
playa	The lowest central portion of an arid basin that is dry and totally barren most of the time, but is occasionally flooded. Clay and silt are the principal constituents, often resulting from lakes formed in Pleistocene time.
Pleistocene	The first epoch before the Holocene of the Quaternary Period.

Pliocene	The latest epoch of geologic time in the Tertiary Period, preceded by the Miocene Epoch and followed by the Pleistocene Epoch.
plug (geologic)	(1) The vertical pipe-like magnetic body representing the conduit of a former volcanic vent. (2) A crater filling of lava, the surrounding material of which has been removed by erosion. (3) A mass of clay, sand, or other sediment filling the part of a stream channel abandoned by the formation of a cutoff.
plug (shaft or borehole)	A watertight seal in a shaft formed by removing the lining and inserting a concrete and/or metal dam, or by placing a plug of clay over ordinary debris used to fill the shaft up to the location of the plug.
pluvial	Said of a geologic episode, change, process, deposit, or feature resulting from the action or effects of rain. Also said of a climate characterized by relatively high amounts of precipitation. More broadly, pertaining to rain or other form of precipitation.
point source	A source of effluents small enough to be treated as if it were a point.
poison	Any material that has a high neutron-absorption cross section and, by absorbing neutrons unproductively, removes them from the fission chain reaction, thus decreasing the radioactivity.
Poisson's ratio	The ratio of the lateral unit strain to the longitudinal unit strain in a body that has been stressed longitudinally within its elastic limit.
population center	A densely populated area of 25,000 or more inhabitants.
population dose	The sum of the radiation doses received by the individual members of a population exposed to a particular source or event. It is expressed in units of man-rem.
pore	Any small open space, generally one that admits the passage or absorption of liquid, within the rock or soil.
porosity	The ratio of the total volume of interstices in rock or soil to its total volume, usually expressed as a percentage.
porosity log	A record of pore volume per unit volume of formation; it is made from a sonic log, density log, neutron log, or resistivity log.
porphyritic	A texture of igneous rock in which large crystals are set in a finer groundmass that may be crystalline or glassy or both.

postclosure	Of or pertaining to the time, conditions, or events after the closure of the repository.
potable water	Water that is safe and palatable for human use.
potentially acceptable site	Any site at which, after geologic studies and field mapping but before detailed geologic data gathering, the DOE undertakes preliminary drilling and geophysical testing for the definition of site location.
potentially adverse condition	A condition that is presumed to detract from expected system performance unless further evaluation, additional data, or the identification of compensating or mitigating factors indicates that its effect on the expected performance of the repository system is acceptable.
potentially disruptive processes and events	Natural processes and events or processes and events initiated by human activities, affecting the geologic setting that are judged to be reasonably unlikely during the period over which the intended performance objective must be achieved, but are nevertheless sufficiently credible to warrant consideration.
potentiometric surface	The surface to which water from a given aquifer will rise by hydrostatic pressure. This surface is usually represented as a contour map in which each point tells how high the water would rise in a well tapping that aquifer at that point.
Precambrian	All geologic time, and its corresponding rocks, that elapsed before the beginning of the Paleozoic era (the Paleozoic era began about 570 million years ago).
precipitation (geochemical)	The process by which mineral constituents are separated from magma or from a solution by evaporation to form igneous rocks.
preclosure	Of or pertaining to the time, activities, operations, and conditions before and during the closure of the repository.
pressurized water reactor	A nuclear reactor that uses pressurized water to generate electricity.
pre-waste-emplacement	Of or pertaining to geologic conditions before waste emplacement.
primary sector	The businesses that predominantly sell their goods and services to individuals and businesses outside the local economy. (See "secondary sector.")

prime farmland	Land with the best physical and chemical characteristics for producing agricultural crops with minimum use of fuel, fertilizers, pesticides, and labor and without intolerable soil erosion, as determined by the Secretary of Agriculture pursuant to the Farmland Protection Policy Act of 1982 (Public Law 97-98). Prime farmland includes land that has these characteristics and is being used to produce livestock and timber, but it excludes land already in, or committed to, urban development or water storage.
probable maximum flood	A statistical representation of the greatest flood expected ever to occur at a specific location.
probable maximum precipitation	A statistical representation of the most precipitation that can reasonably be expected in a given area.
protected area	An area encompassed by physical barriers and to which personnel access is controlled.
protected species	Plants and animals officially listed by the U.S. Fish and Wildlife Service. Species listed by the States as rare, threatened, or endangered are not included unless they are also on the Federal list.
pyroclast	An individual particle ejected during a volcanic eruption.
quadrangle (geologic)	A tract of country represented by one of a series of map sheets published by the U.S. Geological Survey.
qualified site	A site that, having been characterized, is considered to be technically suitable for a repository.
qualifying condition	A condition that must be satisfied for a site to be considered acceptable with respect to a specific siting guideline.
quality assurance	All the planned and systematic actions necessary to provide adequate confidence that a structure, system, or component is constructed to plans and specifications and will perform satisfactorily.
quality control	Quality-assurance actions that provide a means to control and measure the characteristics of an item, process, or facility to established requirements.
quartz	Crystalline silica (SiO_2); an important rock-forming mineral.
quartzite	A metamorphic rock consisting mainly of quartz grains of equal size, formed by the recrystallization of sandstone by regional or thermal metamorphism.
Quaternary faults	Faults that formed or experienced movement during the Quaternary Period.

Quaternary Period	The second part of the Cenozoic Era (after the Tertiary), beginning about 1.8 million years ago and extending to the present.
rad	The basic unit of the absorbed dose of ionizing radiation. A dose of 1 rad equals the absorption of 100 ergs of radiation energy per gram of absorbing material.
radiation (ionizing)	Particles and electromagnetic energy emitted by nuclear transformations that are capable of producing ions when interacting with matter; gamma rays and alpha and beta particles are primary examples.
radiation zone	An area that contains radioactive materials or radiation field in quantities significant enough to require the control of personnel entry to the area.
radioactive decay	See "decay."
radioactive material	In general, any material that spontaneously emits nuclear particles or rays from the nuclei of its atoms.
radioactive waste	High-level radioactive waste, spent nuclear fuel, and other radioactive materials that are received for emplacement in a geologic repository.
radiological risk	A risk derived from exposure to radioactive materials.
radiolysis	The decomposition (splitting) of a chemical molecule (often the water molecule) by exposure to radiation.
radiometric dating	The calculation of the age of a material by a method that is based on the decay of radionuclides that occur in the material.
radionuclide	An unstable radioactive isotope that decays toward a stable state at a characteristic rate by the emission of ionizing radiation.
radionuclide retardation	The process or processes that cause the time required for a given radionuclide to move between two locations to be greater than the ground-water-travel time because of physical and chemical interactions between the radionuclide and the geohydrologic unit through which the radionuclide travels.
rain shadow	A very dry region on the lee side of a topographic obstacle, usually a mountain range, where the rainfall is noticeably less than that on the windward side.

reasonably achievable	Mitigation measures or courses of action shown to be reasonable considering the costs and benefits in accordance with the National Environmental Policy Act of 1969. (See "as low as reasonably achievable.")
reasonably available technology	Technology which exists and has been demonstrated, or for which the results of any requisite development, demonstration, or confirmatory testing efforts before application will be available within the required time periods.
reasonably foreseeable releases	Releases of radioactive wastes to the accessible environment that are estimated to have more than one chance in 100 of occurring within 10,000 years.
recharge (hydrologic)	The process by which water is absorbed and added to the zone of saturation, either directly into a geologic formation, indirectly by way of another formation, or indirectly through unconsolidated sediments.
recharge area	In ground-water hydrology, the area where surface water enters an aquifer.
redox	See "oxidation-reduction reaction."
reduction (chemical)	A decrease in the oxidation state of an element or chemical compound.
redundant equipment or system	Any piece of equipment or any system that duplicates the essential function of any other piece of equipment or system and can perform the entire function regardless of the operating state of the other.
refraction (of sound)	The process of changing the direction of sound propagation by spatial variation in the speed of sound.
regulated area	An area to which access is limited or controlled.
regulatory agency	The government agency responsible for regulating the use of sources of radiation or radioactive materials or emissions and responsible for enforcing compliance with such regulations.
regulatory guide	One of a series of official Nuclear Regulatory Commission guides prescribing standards and recommendations for nuclear facilities.
relative porosity	The ratio of the aggregate volume of interstices in a rock or soil to its total volume. It is usually stated as a percentage.
release limit	A regulatory limit on the concentration or amount of radioactive material released to the environment; usually expressed as a radiation dose.

rem	A unit dose of ionizing radiation that has the same biological effect as 1 roentgen of x-rays; 1 rem approximately equals 1 rad for x-, gamma, or beta radiation. Thus, a rem is a unit of individual dose that allows a comparison of the effects of various radiation types as well as quantities.
remotely handled transuranic waste	Transuranic waste that requires shielding in addition to that provided by its container in order to protect people nearby.
repository	See "geologic repository."
repository closure	See "closure."
repository construction	All excavation and mining activities associated with the construction of shafts, shaft stations, rooms, and necessary openings in the underground facility, preparatory to radioactive-waste emplacement, as well as the construction of necessary surface facilities, but excluding site-characterization activities.
repository horizon	The horizontal plane within the host rock where the location of the repository is planned.
repository operation	All of the functions at the site leading to and involving radioactive-waste emplacement in the underground repository, including receiving, transporting, handling, emplacing, and, if necessary, retrieving the waste.
repository support facilities	All permanent facilities constructed to support site characterization and repository construction, operation, and closure, including surface structures, utility lines, roads, railroads, but excluding the underground repository.
repository system	The geologic setting at the site, the waste package, and the repository, all acting together to contain and isolate the waste.
reprocessing	See "fuel reprocessing."
residual saturation	The minimum saturation that occurs due to gravitational forces alone in the absence of recharge.
residual uncertainty	Those inherent uncertainties in data, modeling, and assumed future conditions that cannot be eliminated.
restricted area	Any area to which access is controlled by the DOE for purposes of protecting of individuals from exposure to radiation and radioactive materials before repository closure, but not including any areas used as residential quarters, although a separate room or rooms in a residential building may be set apart as a restricted area.

retention pond	An earthen structure designed to hold stormwater runoff; sometimes used to mean an evaporation pond.
retrievability	The capability to remove waste from its place of isolation in accordance with preestablished criteria for the method and the rate of removal.
retrieval	The act of intentionally removing radioactive waste before repository closure from the underground location at which the waste had been previously emplaced for disposal.
reverse fault	A fault in which the hanging wall appears to have moved upward relative to the footwall.
rhyolitic	Characteristic of a group of extrusive igneous rocks, generally porphyritic and exhibiting flow texture with crystals of quartz and alkali feldspar in a glassy to cryptocrystalline groundmass (rhyolite).
Richter magnitude	See "Richter scale."
Richter scale	A scale for measuring the energy released by an earthquake. It was devised in 1935 by the seismologist C. F. Richter.
rift (geologic)	A long, narrow trough of regional extent, bounded by normal faults, often associated with volcanism.
right-lateral fault	A fault, the displacement of which is right-lateral separation. In plan view, the apparent movement of the side opposite the observer is to the right.
right-lateral offset	See "right-lateral fault."
rim syncline	In salt tectonics, a local depression that develops as a border around a salt dome, as the salt in the underlying strata is displaced toward the dome.
riparian	Relating to or living or located on the bank of a natural water course (e.g., a river).
risk	The product of the probability and the consequences of an event.
rock bolt	A bar, usually constructed of steel, that is anchored into predrilled holes in rock as a support device.
rock burst	A sudden yielding that occurs when a volume of rock is strained beyond its elastic limit and the accompanying failure is such that the accumulated energy is released instantaneously. A rock burst can vary from the splitting off of small slabs of rock from a mine wall to the collapse of large pillars, roofs, or other massive parts of a mine.

rock-mass quality	A description of the physical characteristics and mechanical behavior of the rock mass. Rock-mass quality classifications are applied empirically to estimate requirements for underground-excavation support and mechanical properties like the strength and deformation modulus of the rock mass.
room-and-pillar mining	A system of mining in which the rock is mined in rooms separated by pillars of undisturbed rock left for roof support.
rubble	Loose, unconsolidated rock consisting mostly of large, angular rocks intermixed with a small amount of soil or earthy material.
rulemaking	Process of formulating specific regulations governing a particular matter.
sabkha	An environment of sedimentation, formed under arid to semiarid conditions on restricted coastal plains just above normal high-tide level. Sabkhas are characterized by evaporite salt and tidal-flood and wind-blown deposits.
salt	The common mineral sodium chloride (NaCl) and any impurities in it.
salt creep	See "creep."
sandstone	Variously colored sedimentary rock composed mainly of sandlike quartz grains cemented by lime, silica, or other materials.
saturated zone	That part of the earth's crust beneath the water table in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric.
scabland	An elevated area, underlain by flat-lying basalt flows, with a thin soil cover and sparse vegetation that is crossed by coulees.
scaling	The removal of loose rock from a newly blasted wall or roof.
scanning-transmission electron microscope	A type of electron microscope that scans with an extremely narrow beam of electrons transmitted through the sample; the detection apparatus produces an image whose brightness depends on the atomic number of the sample.
scarification	The process of breaking up and loosening the surface of a material.
scenario	A particular chain of hypothetical circumstances often used in performance analysis to model possible events.

scenario analysis	Analytical process that attempts to quantify the probabilities and consequences of a postulated sequence of events.
scouring	Erosion, especially by moving water.
screening	The process of evaluating an area on the basis of criteria or guidelines to identify places that best fulfill the criteria or guidelines.
seal	An engineered barrier to prevent radionuclide migration or the intrusion of undesirable substances.
secondary compression	The reduction in volume of sediments under constant pressure that results from changes in the internal structure of the sediments.
secondary sector	The sectors of the economy that serve local residents and businesses. (See "primary sector.")
sedimentary rock	Rock formed of sediment, especially (a) clastic rocks (e.g., conglomerates, sandstone, and shales) formed of fragments of other rock transported from their sources and deposited in water and (b) rocks formed by precipitation from solution (e.g., rock salt and gypsum) or from the secretions of organisms (e.g., most limestones).
seismic	Pertaining to, characteristic of, or produced by earthquakes or earth vibrations.
seismic reflection line	A line on the earth's surface along which a seismic reflection survey is conducted.
seismic reflection survey	A survey based on measurement of the travel times of waves that originate from an artificially produced disturbance and are reflected back to the surface at nearly vertical incidence from boundaries separating media of different elastic-wave velocities.
seismic refraction survey	A survey based on the measurement of the travel times of seismic waves that have moved nearly parallel to the bedding in high-velocity layers.
seismic survey	Seismic data gathered from an area.
seismicity	The occurrence of earthquakes or the spatial distribution of earthquake activity. Also the phenomenon of earth movement.
seismometer	An instrument that receives seismic impulses and converts them into electrical voltage or otherwise makes them evident. Also known as a geophone.

shaft	With regard to a geologic repository, the penetration of the natural isolation barrier to provide access to subsurface facility; it is usually of limited cross-sectional area compared to its depth. A more common definition is a manmade hole, either vertical or steeply inclined, that connects the surface with the underground workings of a mine or excavation. The difference between a shaft and a borehole is primarily in size and use.
shaft liner	A structural lining usually made of steel, concrete, or timber that provides safe rock support and aids in preventing ground water from entering the shaft.
shaft pillar	An undisturbed buffer zone surrounding a shaft of sufficient area, so that any possible subsidence in nearby mined areas will not disturb the integrity of the shaft facility.
shaft seal system	The devices, mechanisms, or materials used or emplaced between the shaft liner and the rock wall during operation or shaft closure to retard the flow of liquid or gas.
shaft station	A horizontally excavated opening of a shaft at a desired depth.
shale	A fine-grained detrital sedimentary rock formed by the compaction of clay, silt, or mud.
shear	(1) A strain that causes contiguous parts of a body to slide relative to each other in a direction parallel to their plane of contact. (2) Surfaces and zones of failure by shear or surfaces along which differential movement has taken place.
shear resistance	The internal resistance of a body to shear stress, typically including a frictional part and a part independent of friction called "cohesion." Also called "shear strength."
shear zone	A tabular zone of rock that has been crushed and brecciated by many parallel fractures due to shear strain.
sheave	A large, pulley-type wheel at the top of the headframe that carries the hoist rope.
shield rocks	Areas of exposed basement rocks in a craton commonly with a very gently convex surface, surrounded by sediment-covered platforms.
shielding	The material interposed between a source of radiation and personnel to protect against radiation exposure; commonly used shielding materials are concrete, water, and lead.

shipping cask	A large, heavily shielded vessel for transporting fuel assemblies and radioactive waste. The cask provides physical protection to the contents and radiation protection to its surroundings. Radioactive waste is transported to the repository in shipping casks.
shotcrete	Cement-based compounds sprayed onto mine surfaces to prevent erosion by air and moisture and onto rock surfaces to stabilize against minor rock falls. Also used to prevent dehydration and decrepitation.
shrub-steppe	Distinguished from a true steppe by the presence of forbes, shrubs, and a few trees in an extensive grassland area. Generally not as dry as a steppe.
significant source of ground water	As defined in 40 CFR Part 191, an aquifer that (1) is saturated with water having less than 10,000 milligrams per liter of total dissolved solids, (2) is within 770 meters (2,500 feet) of the land surface, (3) has a transmissivity greater than 3×10^{-5} square meter per second (200 gallons per foot per day), provided that any formation or part of a formation included within the source of ground water has a hydraulic conductivity greater than 1×10^{-6} meter per second (2 gallons per square foot per day), and (4) is capable of continuously yielding at least 1,600 liters per hour (10,000 gallons per day) to a pumped or flowing well for a period of at least a year; or an aquifer that provides the primary source of water for a community water system.
silica	A chemically resistant oxide of silicon (SiO_2).
silicification	The introduction of, or replacement by, silica, generally resulting in the formation of fine-grained quartz, chalcedony, or opal, which may fill pores and replace existing minerals.
sill (geologic)	A tabular igneous intrusion that parallels the planar structure of the surrounding rock.
silt	A sedimentary material consisting of five mineral particles intermediate in size between sand and clay.
siltstone	Stone composed of hardened stone.
sinkhole	An opening at the earth's surface caused by the collapse of rock above a solution zone where ground water has moved along a joint or fracture system and has washed out or dissolved underlying material, such as limestone.
site	A potentially acceptable site or a candidate site, as appropriate, until such time as the controlled area has been established, at which time the site and the controlled area are the same.

site characterization	Activities, whether in the laboratory or in the field, undertaken to establish the geologic conditions and the ranges of the parameters of a candidate site relevant to the location of a repository, including borings, surface excavations, excavations of exploratory shafts, limited subsurface lateral excavations and borings, and in situ testing needed to evaluate the suitability of a candidate site for the location of a repository, but not including preliminary borings and geophysical testing needed to assess whether site characterization should be undertaken.
siting	All of the exploration, testing, evaluation, and decisionmaking associated with site screening, site nomination, site recommendation, and site approval for characterization or repository development.
siting guidelines	General guidelines for siting geologic repositories; issued by the Department of Energy as 10 CFR Part 960.
slabbing	A stress-induced failure mechanism of the rock around an excavation.
slash	A mining technique in which a large-diameter drilled hole is enlarged by using the drill-and-blast method.
slickensides	Polished and smoothly striated surfaces that result from friction along a fault plane.
slip	The relative displacement of formerly adjacent points on opposite sides of a fault, measured in the fault surface.
slough	Fragments of rock material from the wall of a borehole that are washed out of the hole with the return pipeline.
sloughing	The falling of loosened rock from the roof or walls of and underground excavation.
slump (geologic)	The downward slipping of a mass of rock or unconsolidated material of any size, moving as a unit or as several subsidiary units, usually with backward rotation on a more or less horizontal axis parallel to the cliff or slope from which it descends.
slurry	A fluid mixture of water and finely divided material.
smectite	A group of expanding-lattice clay minerals. These minerals are common in soils, sedimentary rocks, and some mineral deposits and are characterized by swelling in water and extreme colloidal behavior.
solubility	The amount of substance (i.e., an element or compound) that can be dissolved in a given amount of solvent.

solute	A substance dissolved in another substance, usually the component of a solution present in the lesser amount.
sonic log	A geophysical log made by an instrument, lowered and raised in a borehole or well, that continuously records, as a function of depth, the velocity of sound waves as they travel over short distances in the adjacent rocks. The log reflects lithologic changes.
sorption	The binding, on a microscopic scale, of one substance to another, such as by adsorption or ion exchange. Here "sorption" is used for the sorption of dissolved radionuclides onto aquifer solids or waste-package materials by chemical or physical forces.
sorptive capacity	The measure of a material's ability to sorb specific constituents from a liquid as it passes through the material.
source term	The types and amounts of radionuclides that make up the source of a potential release of radioactivity.
specific activity	The measure of radioactivity as a function of mass. The unit of specific activity is curie per gram.
specification	A concise statement of a set of requirements prescribing materials, dimensions, or workmanship for something to be built or manufactured.
specific heat	The quantity of heat necessary to raise the temperature of 1 gram of a given substance 1 degree Celsius.
specific yield	The ratio of the volume of water that a given mass of saturated rock or soil will yield by gravity to the volume of that mass.
spent fuel	Nuclear fuel that has been removed from a reactor after irradiation and has not been reprocessed to recover uranium and plutonium.
spherulitic	Said of a rock composed of numerous rounded or spherical masses of needlelike crystals, radiating from a central point.
spoils	The debris or waste material from a mine. The rock and other natural materials brought up to the surface during mining. Also called "mined materials" or "mined rock."

stability, repository	The condition resulting from the nature and rates of natural processes affecting the site during the recent geologic past and the expectation that they will be relatively slow and will not significantly change during the next 10,000 years or jeopardize the isolation of the waste. As defined in 10 CFR Part 60, the nature and rates of natural processes (e.g., erosion and faulting) have been and are projected to be such that their effects will not jeopardize the isolation of the waste.
stability of rock structure	The capability of an opening at depth to retain its original shape for a length of time. Stability is related to the quality of the rock mass around the opening, including slabbing and fracture.
standard metropolitan statistical area (SMSA)	One or more contiguous counties containing at least one city of 50,000 inhabitants or more. Additional counties have to meet criteria related to metropolitan character and socioeconomic integration with the central city.
steel sets	Support beams used in mine roofs and walls.
steppe	An extensive treeless grassland area that is developing in the semiarid midlatitudes of southeastern Europe and Asia. Also used to describe similar areas in other parts of the world.
stochastic model	A model whose inputs are uncertain and whose outputs are therefore also uncertain and must be described by probability distributions.
storage coefficient	The volume of water an aquifer releases from, or takes into storage, per unit surface area of the aquifer and per unit change in head.
storativity	The volume of water released from storage in a vertical column of 1 square foot when the water table or other piezometric surface declines 1 foot. In an undefined aquifer, it is approximately equal to the specific yield.
strain	(1) Change in the shape or volume of a body as a result of stress. (2) A change in the relative configuration of the particles of a substance.
stratigraphic setting	The characteristics of the rock layers or other units in the geologic environment.
stratigraphy	The branch of geology that deals with the definition and interpretation of the rock strata, the conditions of their formation, character, arrangement, sequence, age, distribution, and especially their correlation by the use of fossils and other means of identification.

stratum	A single bed or layer of rock regardless of thickness.
stress	In a solid, the force per unit area acting on any surface within it and variously expressed as pounds or tons per square inch, or dynes or kilograms per square centimeter; also, by extension, the external pressure that creates the internal force.
strike	The direction or trend of a structural surface (e.g., a bedding or fault plane) as it intersects the horizontal.
strike-slip fault	A fault in which the net slip is horizontal or parallel to the strike of the fault (see also "dip-slip fault").
stringer	A narrow vein or irregular filament in a rock mass of different material.
student's t test	A standard statistical method used for hypothesis testing and normally used with a sample size of less than 30.
subsidence	Sinking or downward settling of the earth's surface, not restricted in rate, magnitude, or area involved.
subsurface facility	See "underground facility."
sump	A pit or depression serving as a drain or reservoir for liquids.
surface facilities	Repository support facilities in the restricted area.
surface water	Any waters on the surface of the earth, including fresh and salt water, ice, and snow.
surge capacity	The capacity to accommodate radioactive materials by temporary storage at the repository.
system	See "repository system."
system performance	The complete behavior of a repository system in response to the conditions, processes, and events that may affect it.
talus	Loose rock fragments of any size or shape derived from, and lying at, the base of a steep slope.
tectonic	Of, or pertaining to, the forces involved in tectonics or the resulting structures or features.
tectonic activity	Movement of the earth's crust such as uplift and subsidence and the associated folding, faulting, and seismicity.

tectonic breccia	A breccia formed as the result of crustal movements, usually developed in brittle rocks. Slickensides are commonly associated with tectonic breccia, and varying amounts of claylike gouge may be present.
tectonic features	Features such as fault gouge, faulted, and folded rock.
tectonic fractures	Fractures that may or may not have slickensides on their adjoining surfaces and are commonly associated with tectonic breccias. Includes fractures across which no measurable movement has occurred.
tectonic model	A nonnumerical, descriptive theory or concept that incorporates geological, geophysical, and geodetic data into a satisfactory explanation of the evolution of stress and strain in the earth's crust; it can be used to make estimates of future crustal processes.
tectonic province	A region of the earth's crust with relatively consistent structural geologic features.
tectonism	Crustal movement produced by earth forces, such as the formation of plateaus and mountain ranges; the structural behavior of an element of the earth's crust.
tectonics	A branch of geology dealing with the broad architecture of the outer part of the earth; that is, the regional assembling of structural or deformational features, a study of their mutual relations, their origin, and their evolution.
tensile strength	The ability of a material to resist a stress tending to stretch it or to pull it apart.
Tertiary	The earlier of the two geologic periods that make up the Cenozoic Era, extending from 65 million to 1.8 million years ago.
thermal conductivity	A measure of the ability of a material to conduct heat.
thermal decrepitation	The shattering of a rock mass or rock sample caused by the heat-induced buildup of excessive pressures in contained fluids.
thermal expansion	The increase in linear dimensions that occurs when materials are heated.
thermal gradient	The rate of change in temperature with distance.
thermal loading	The application of heat to a system, usually measured in watt density. The thermal loading for a repository is the watts per acre produced by the radioactive waste in the active disposal area.

thermoluminescent dosimeter	A type of radiation measuring device that contains thermoluminescent material that emits light when subjected to heat. The amount of light emitted is directly proportional to the radiation dose absorbed by the chip.
threatened species	Any plant or animal species protected by Public Law 93-205 that is likely to become endangered in the foreseeable future throughout all or a portion of its range.
thrust fault	A fault with a dip of 45 degrees or less in which the hanging wall appears to have moved upward relative to the foot wall.
to the extent practicable	The degree to which an intended course of action is capable of being effected in a manner that is reasonable and feasible within a framework of constraints.
topography	The branch of geology dealing with the configuration of the land surface, including its relief and the position of natural and man-made features. Also used synonymously with "terrain."
tortuosity	The inverse ratio of the length of a rock specimen to the length of the equivalent path of water within it.
tracer testing	A procedure in which a soluble substance (tracer) is added to ground-water at one location and its movement to another location is observed. Tracer testing is a technique by which ground-water flow directions and velocities and other hydrologic properties of rocks can be estimated.
transfer cask	A cask that provides shielding for the waste disposal container as it is transferred from the waste-handling buildings for emplacement underground.
transgressive sea	A sea that has encroached on the land.
transmissivity	The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It equals the hydraulic conductivity multiplied by the thickness of the aquifer.
transport path	A route along which radionuclides could migrate.
transuranic waste	Waste containing more than a specific concentration of alpha-emitting radionuclides (including uranium-233 and its daughter products) of long half-life and high specific radiotoxicity. This concentration is currently defined as more than 100 nanocuries per gram of waste.

transuranics	Elements with an atomic number higher than 92. They do not normally occur in nature and have to be produced artificially from uranium.
tridymite	A mineral, SiO_2. It is a high-temperature form of quartz and usually occurs as minute, tabular, white or colorless crystals or scales in cavities in acidic volcanic rocks.
tritium	A radioactive isotope of hydrogen with two neutrons and one proton in the nucleus.
tubbing	Cast-iron liner plates for shafts, fabricated to specification, that bolt together to give support to rock.
tufa	A sedimentary rock composed of calcium carbonate, formed by evaporation as an incrustation around the mouth of a spring, along a stream, or around a lake.
tuff	A rock formed of compacted volcanic ash and dust.
tuffaceous	Said of sediments containing up to 50 percent tuff.
unconfined aquifer	An aquifer containing ground water that has a water table or upper surface at atmospheric pressure.
unconformity (geologic)	A break or gap in the geologic record, such as an interruption in the normal sequence of deposition of sedimentary rocks, or a break between eroded metamorphic rocks and younger sedimentary strata.
underground facility	The underground structure and the rock required for support, including mined openings and backfill materials, but excluding shafts, boreholes, and their seals.
unit of local government	Any borough, city, county, parish, town, township, village, or other general-purpose political subdivision of a State.
unrestricted area	Any area that is not controlled for the protection of individuals from exposure to radiation and radioactive materials.
unsaturated zone	The zone between the land surface and the water table. Generally, water in this zone is under less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or perched-water bodies, the water pressure locally may be greater than atmospheric.
uplift (geologic)	(1) The process that results in the elevation of a portion of the earth's crust. (2) A structurally high area in the crust produced by movements that have raised or upthrust the rocks, as in a dome or an arch.

upwarping	The uplift of a regional area of the earth's crust, usually as a result of the release of isostatic pressure (e.g., the melting of an ice sheet).
urban area	As defined for use in the 1980 census, incorporated and unincorporated places of 2,500 inhabitants or more.
vadose water	Water of the zone of aeration (unsaturated zone). Also known as "suspended water."
vadose zone	The unsaturated region of soil or the zone of aeration between the ground surface and the water table.
validation of computer codes and models	A process whose objective is to ascertain that the code or model indeed reflects the behavior of the real world.
vent system	A group of generally parallel fissures from which lava came to the surface.
verification of computer codes and models	Testing a code with analytical solutions for idealized boundary-value problems. A computer code will be considered verified when it has been shown to solve the boundary-value problems with sufficient accuracy.
very near field	The waste package and the rock within approximately 3 feet of the waste packages emplaced in a repository.
very unlikely releases	Releases of radioactive wastes to the accessible environment that are estimated to have between one chance in 1,000 and one chance in 10,000 of occurring within 10,000 years.
vesicle	A small cavity in an igneous rock, formed by the expansion of a bubble of gas or steam during the solidification of the rock.
vitrophyre	Any porphyritic igneous rock with a glassy groundmass.
volcanic glass	Natural glass produced by the cooling of molten lava or some liquid fraction of molten lava too rapidly to permit crystallization.
volcanism	The processes by which magma and its associated gases rise into the crust and are extruded onto the earth's surface and into the atmosphere.
voucher collection	A collection of dried plant specimens usually mounted and systematically arranged for reference; a piece of supporting evidence.
vug	A cavity, often within a mineral lining of different composition from that of the surrounding rock.

waste	As used in this document, high-level radioactive waste or spent fuel.
waste canister	See "canister."
waste container	See "container."
waste form	The radioactive waste materials and any encapsulating or stabilizing matrix.
waste management	The planning, execution, and surveillance of essential functions related to the control of radioactive (and nonradioactive) waste, including treatment, solidification, packaging, transportation, initial or long-term storage, surveillance, disposal, and isolation.
waste matrix	The material that surrounds and contains the waste and to some extent protects it from being released into the surrounding rock and ground water. Only material within the canister (or drum or box) that contains the waste is considered part of the waste matrix.
waste package	The waste form and any containers, shielding, packing, and other sorbent materials immediately surrounding an individual waste container.
water budget	The quantification of the amount of water entering, moving through, and leaving a flow system; sometimes called "water balance."
water flux	A stream of flowing water; flood or outflow of water.
watershed	A drainage basin.
water table	The water surface in a body of ground water at which the water pressure is atmospheric.
welded tuff	Indurated volcanic ash in which the constituent glassy shards and other fragments have become welded together, apparently while still hot and plastic after deposition. Where the distinction between nonwelded and partly welded tuff is necessary, the boundary should be placed at or close to that point where the deformation of glassy fragments becomes visible. The transition from partly to densely welded tuff is one of progressive loss of pore space accompanied by an increase in the deformation of the shards and pumiceous fragments.
wind rose	A diagram showing the distribution with direction of the frequency and the speed of the wind.
worst-case analysis	An analysis based on assumptions and input data selected to yield a "worst impact" statement.

x-ray diffraction analysis	Analysis of the crystal structure of materials by passing x-rays through them and registering the diffraction (scattering) image of rays.
xenolith	An inclusion in an igneous rock to which it is not genetically related.
Young's modulus	A modulus of elasticity in tension or compression, involving a change in length.
zeolites	Any of various silicates analogous in composition to the feldspars and occurring as secondary minerals in cavities, along fractures, and on joint planes in basaltic lavas. Occur also as authigenic minerals in sedimentary rocks.

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ACFM	actual cubic feet per minute
ACHP	Advisory Council on Historic Preservation
ACR	area characterization report
Act	Nuclear Waste Policy Act of 1982
ADT	average daily traffic volume
A/E	architect-engineer
AEC	Atomic Energy Commission
ALARA	as low as (is) reasonably achievable
ANSI	American National Standards Institute
AQCR	air quality control region
ATMX	code of special railcar used in shipping defense wastes
AUM	animal-unit month
BAT	best available technology
BHA	bottom hole assembly
BLM	Bureau of Land Management (U.S. Department of the Interior)
BP	before present
BWIP	Basalt Waste Isolation Project
BWR	boiling-water reactor
C	Centigrade
C&C	consultation and cooperation
CEQ	Council on Environmental Quality (council which administers the National Environmental Policy Act)
CFR	Code of Federal Regulations
CHLW	commercial high-level waste

CH-TRU	contact-handled transuranic waste
COE	Corps of Engineers (U.S. Army)
COG	Council of Governments
CRRD	Conceptual Reference Repository Description
CRWM	Civilian Radioactive Waste Management (Program) (formerly NWB)
D&E	Design and Engineering
D&D	decontamination and decommissioning
DB	drill-and-blast (method of exploratory shaft construction)
dB	decibel
dBA	A-weighted decibels (sound pressure levels)
DBE	design basis earthquake or event
DBF	design basis flood
DBT	design basis tornado
DEIS	draft environmental impact statement
DHLW	defense high-level waste
DOC	U.S. Department of Commerce
DOE	U.S. Department of Energy
DOE/NPO	U.S. Department of Energy, National Waste Terminal Storage Program Office (former)
DOE/SRPO	U.S. Department of Energy, Salt Repository Project Office (previously NPO)
DOI	U.S. Department of the Interior
DOT	U.S. Department of Transportation
DST	drill stem test
EA	environmental assessment
ECR	environmental characterization report

EDB	engineering data borehole
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
ES	exploratory shaft
ESF	exploratory shaft facility
F	Fahrenheit
FEIS	final environmental impact statement
FR	Federal Register
FRP	fuel reprocessing plant
FSAR	final safety analysis report
FWS	U.S. Fish and Wildlife Service
GD	Gibson Dome (borehole)
GEIS	generic environmental impact statement
gpm	gallons per minute
GROA	geologic repository operations area
GSA	General Services Administration
HAW	high-activity waste
HEPA	high-efficiency particulate air (filter)
HLW	high-level waste
HMTA	Hazardous Materials Transportation Act
hp	horsepower
HVAC	heating, ventilating, and air conditioning
IAEA	International Atomic Energy Agency
ICC	Interstate Commerce Commission

ICRP	International Commission on Radiological Protection
ILW	intermediate-level waste
L_{dn}	day-night weighted equivalent sound level measurement
L_{eq}	24-hour energy equivalent noise level measurement
LHD	large-hole drilling
LLW	low-level waste
MM	modified Mercalli (scale)
MPC	maximum permissible concentration
mrem	millirem
MRS	monitored retrievable storage
MSHA	Mine Safety and Health Administration
MSL	mean sea level
MTHM	metric tons of heavy metal
MTU	metric tons of uranium
NA	not applicable
NAAQS	National Ambient Air Quality Standards
NAS	National Academy of Sciences
NBS	National Bureau of Standards
NCRP	National Council on Radiation Protection and Measurements
NEPA	National Environmental Policy Act of 1969
NIOSH	National Institute of Occupational Safety and Health
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRC	U.S. Nuclear Regulatory Commission; National Research Council
NRHP	National Register of Historic Places

NSP	National Siting Plan
NTS	Nevada Test Site
NWPA	Nuclear Waste Policy Act of 1982 (Public Law 97-425)
NWTS	National Waste Terminal Storage (Program) (former name; replaced by Civilian Radioactive Waste Management Program)
OCRWM	Office of Civilian Radioactive Waste Management
ONWI	Office of Nuclear Waste Isolation
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
OWI	Office of Waste Isolation
PABX	private automatic branch exchange
PAC	potentially adverse condition
PL	Public Law
PMF	probable maximum flood
ppm	parts per million
PNL	Pacific Northwest Laboratory
PSD	prevention of significant deterioration (air quality standards)
PUREX	plutonium and uranium recovery through extraction
PWR	pressurized-water reactor
QA	quality assurance
QC	quality control
RAD	radiation absorbed dose
RCRA	Resource Conservation and Recovery Act of 1976
rem	roentgen equivalent in man

SARP	safety analysis report for packaging
SCFM	standard cubic foot per minute
SCP	site characterization plan
SCR	site characterization report
SEARS	Socioeconomic Assessment for Repository Siting (model)
SFPWR	spent fuel from pressurized boiler reactors
SHPO	state historic preservation offices
SJC-WCD	San Juan County Water Conservation District
SMSA	standard metropolitan statistical area
SRPO	Salt Repository Project Office
SRR	site recommendation report
Supply System	Washington Public Power Supply System
T&E	threatened and endangered
TDS	total dissolved solids
TEF	test and evaluation facility
TRU	transuranic (contaminated)
TSP	total suspended particulates
TWC	Texas Water Commission
UACR	Utah Air Conservation Regulations
UBC	Uniform Building Code
UCWRR	Upper Colorado Water Resource Region
UDOT	Utah Department of Transportation
USACE	U.S. Army Corps of Engineers
USBM	U.S. Bureau of Mines
USC	U.S. Code

USDA	U.S. Department of Agriculture
USDC	U.S. Department of Commerce
USDI	U.S. Department of the Interior
USGS	U.S. Geological Survey
USLE	universal soil-loss equation
UTF	underground test facility
UTM	Universal Transverse Mercator
VRM	visual resource management
WHPF	waste handling and packaging facility
WIPP	Waste Isolation Pilot Plant
WISP	Waste Isolation Systems Panel
WNP	Washington Public Power Supply System Nuclear Project
WPPP	Waste Package Program Plan
WPPSS	Washington Public Power Supply System
WSA	Wilderness Study Area
WVHLW	West Valley high-level waste

Appendix A

TRANSPORTATION

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Appendix A

TRANSPORTATION

A.1 INTRODUCTION

This appendix, which is common to all environmental assessments, presents general background information on transportation topics and issues and provides supplementary references to more-detailed sources of information. The discussions throughout the appendix are specific to the spent-fuel and high-level-waste shipments that will be made to a repository.* The agencies responsible for the regulation of radioactive-material transportation are identified, and their regulations or requirements are reviewed. The shipping casks and cask concepts that will be developed in compliance with the regulatory framework are also described. These topics are discussed in the context of protecting public health and safety against the potential hazards associated with normal transportation, accidents, and sabotage. In addition, the bases for, and the methods of, evaluating the relative transportation risk and cost for each of the sites nominated as suitable for characterization are briefly considered. Separate sections are included to consider the use of barges as an alternative mode of transportation, and to discuss how the consideration of a second repository would affect the results of a single-repository analysis. Also included is a section that describes the criteria developed to aid in the application of the siting guideline on transportation. Finally, several of the major transportation issues (routing, prenotification, emergency reponse, and liability) that have been raised by the public are discussed.

For purposes of discussion in this appendix, the following terms unique to the vocabulary of transportation are defined:

- Packaging (cask) - the assembly of components, excluding contents, that shields and contains the radioactive contents. Packaging may consist of one or more receptacles, absorbent materials, spacing structures, thermal insulation, radiation shielding, and devices for cooling or absorbing mechanical shocks.

- Package - packaging together with its contents as presented for transportation. This term is distinct from "waste package," which denotes the contents of the waste-emplacement hole in the repository.

- Normal transportation - all conditions of transportation except those that result from accidents and sabotage.

Additional lists of transportation terms that may be of interest are found in 49 CFR 171.8, 49 CFR 173.403, and 10 CFR 71.4.

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* For convenience and brevity, the term "radioactive waste" or simply "waste" is often used to mean spent fuel or all of the waste to be accepted by the repository.

A.2 AGENCIES WITH JURISDICTION OVER THE TRANSPORTATION OF RADIOACTIVE WASTE

A.2.1 FEDERAL JURISDICTION

The number of Federal organizations involved in the regulation of radioactive-waste transport is large, and their responsibilities and authorities are interrelated. However, only the functions of the U.S. Department of Transportation (DOT), the U.S. Nuclear Regulatory Commission (NRC), and the U.S. Department of Energy (DOE) are discussed here because of their predominance in radioactive-materials transport. More-detailed information and information about organizations not mentioned can be found in reports by Wolff (1984) and the NRC (1977).

The DOT has regulatory responsibility for safety in the transportation of all hazardous materials, including radioactive materials. This responsibility extends to all modes of transportation that would be considered for shipping waste to the repository. Under its establishing legislation, the Department of Transportation Act of 1966, the DOT is responsible for encouraging cooperation among Federal, State, and local governments, carriers, shippers, labor, and other interested parties to achieve national transportation objectives. The regulatory and enforcement authority of the DOT over the shipments of radioactive material that are in, or may affect, interstate commerce was extended by the Hazardous Materials Transportation Act (HMTA) of 1974 to include, but not be limited to, the packaging of specified types and quantities of radioactive materials, handling, labeling, placarding, routing, and driver training.

The NRC provides supplementary regulations related to the transportation of radioactive material. Under the Atomic Energy Act of 1954, as amended, the NRC has responsibility for safety in the possession, use, and transfer (including transportation) of by-product, source, and special nuclear materials. The NRC licenses commercial entities that possess and use these materials. It also promulgates regulations applicable to NRC-licensees regarding the packagings of specified quantities of highly radioactive materials, prenotification of shipments, and the physical protection of spent-fuel shipments from acts of theft and sabotage. The DOT, by agreement with the NRC, accepts the NRC standards of 10 CFR Part 71 for packagings. This agreement has been formalized in a memorandum of understanding between the two agencies (Federal Register, Vol. 44, p. 38690, July 2, 1979). These standards are now in general agreement with international regulations. To aid in enforcement, the NRC requires its licensees to comply with DOT regulations when those entities are not otherwise subject to the DOT regulations.

The shipments of radioactive material conducted by the DOE are also subject to DOT regulations. Authority has been granted to the DOE by DOT regulations (49 CFR 173.7) to approve and certify packagings made by or under the direction of the DOE, as long as the evaluation, approval, and certification are against packaging standards equivalent to those specified in the NRC regulations in 10 CFR Part 71. Although the DOE will take title to all shipments of spent fuel and will be the shipper of record with the authority to use DOE-certified packages, a procedural agreement (Federal Register, Vol. 48, p. 51875, November 14, 1983) has been signed between the

NRC and the DOE; it provides that the DOE will, while making radioactive-waste shipments from NRC-licensed facilities to facilities established under the Nuclear Waste Policy Act (the Act), use NRC-certified packages. The agreement is currently limited to matters of health and safety incident to packaging.

The Act also restates the requirement that the DOE must comply with DOT regulations. A memorandum of understanding between the DOE and the DOT delineates the respective responsibilities and establishes common planning assumptions that the DOE and the DOT will observe in the implementation of transportation requirements under the Act (Federal Register, Vol. 40, p. 47421, November 18, 1985).

A.2.2 ROLE OF STATES

The States also have an important role in regulating the transportation of radioactive materials. Some States have adopted DOT regulations and apply them to intrastate shipments as well as interstate shipments. A particularly important role of the State under DOT regulations is that of designating preferred highway routes for shipments of the type of radioactive materials that would be shipped under the Act (DOT, 1984). A more complete discussion of the States' roles in highway routing is presented in Section A.13.3.1.

A.3 PARTICIPANTS IN THE SHIPPING PROCESS

Three major participants in the shipping process are subject to existing Federal regulations: the shipper, the carrier, and the receiver. The shipper is responsible for the transfer of the radioactive material even though the material may be physically transported by someone else. The shipper must identify the contents of the package, inform the carrier (the actual transporter) of the contents of the package, and must notify the States through which a shipment will pass. Also, the shipper must perform contamination and radiation-level surveys, prepare shipping papers, and certify on the shipping papers that the package is properly prepared. The shipper is instrumental in ensuring the safety of the shipment. The carrier must placard the vehicle, provide any training that may be required, prepare a route plan, and ensure that prescribed routes are followed. The receiver generally acts to support the shipper by inspecting shipments on arrival and by preparing the transportation vehicle for the return trip, ensuring that contamination levels, if any, are below regulatory limits.

The shipping participants under the Act are expected to be the DOE as the shipper of record (the responsibility of separate offices within the DOE for shipments of defense waste to a repository has not been decided upon yet), commercial transporters as the carriers, and the DOE's Office of Civilian Radioactive Waste Management (OCRWM) as the receiver.

A.4 REGULATIONS RELATED TO NORMAL TRANSPORTATION

The hazards of radioactive-material transportation under normal conditions are minimized by existing regulations. All radioactive materials emit penetrating radiation of varying strength and penetrating power, and shielding is provided in the packaging to reduce this radiation to low levels. Many administrative regulations have been developed to (1) identify packages that contain radioactive material and (2) limit exposures to low levels.

A package must be properly prepared and have proper markings and labels. In addition, a vehicle carrying radioactive material of the type that would be shipped to a repository must be placarded for further identification. A tamper seal is used to show that a shipment has not been opened by unauthorized personnel. Furthermore, the shipper must prepare shipping papers and driver instructions that identify the materials being transported and provide appropriate instructions for shipping.

Limits are prescribed for both temperature and radiation-dose rates. The accessible surface temperatures of packages may not exceed 82°C (180°F). Most likely, the casks for the DOE's waste-management program will be designed to ensure that the radiation-dose rates for shipments to a repository will be at the regulatory limit of 10 mrem/hr at 2 meters (6.6 feet) from the external surface of the vehicle or trailer. A radiation dose equivalent to 1 year's exposure to natural background radiation would be received in 10 to 15 hours if a person were to stand at the 2-meter (6.6-foot) distance. Although these exposures are low, the labels and placards are intended to alert the public and to prevent prolonged inadvertent contact with a shipping vehicle or package.

Since loose radioactive material may adhere to the external surface of the package or the vehicle, external contamination is also monitored to ensure that it does not reach harmful levels.

There are many other regulations that have an important effect on the safety and efficiency of radioactive-material shipments. These regulations include requirements for driver training and qualification, notifications, and safeguards. A good review of current DOT regulations can be found in a recent DOT report (DOT, 1983b). The regulations are found in 49 CFR Parts 100-179. NRC regulations are found in 10 CFR Part 71 and Part 73.

A.5 REGULATIONS RELATED TO MITIGATING THE CONSEQUENCES OF ACCIDENTS

During the period from 1971 to 1981, over 1,500 truck and rail shipments of spent fuel were completed (Newman, 1985), and only 4 accidents occurred (Emerson and McClure, 1983). Two of these accidents occurred when the casks were empty. None of the casks released radioactive material.

The packaging is the primary means of protection in the event of an accident. The stringency of regulations for packagings is related to the hazard of the radioactive contents if they were to be dispersed during an accident. For the radioactive materials that will be shipped to a repository,

packagings must be designed to preclude significant releases even under severe accident conditions. Under the conditions of the vast majority of accidents, packaging design will preclude entirely the release of material. This section discusses design criteria in regulations, while Section A.7 discusses proposed designs of packagings for shipments to a repository.

Among other requirements, packagings for shipments to a repository will have to survive the testing conditions identified in 10 CFR Part 71. These testing conditions have been estimated to be more severe than those encountered in at least 99.9 percent of all transportation accidents (McClure, 1981). By demonstrating the capability to survive such severe conditions, a packaging can be expected to completely contain its contents during an accident, and this has been the experience to date.

The specific tests to which the same packaging is subjected are as follows:

1. A free drop of 9 meters (30 feet) onto an unyielding target.

2. A free drop of 1 meter (40 inches) onto a puncture probe of a specified size.

3. An exposure to an engulfing thermal environment of 800°C (1,475°F) for 30 minutes.

4. An immersion under 0.9 meter (3 feet) of water for 8 hours.

5. An immersion under 15 meters (50 feet) of water for 8 hours (an undamaged packaging may be used for this test).

Information about the basis for these specific tests can be found in a report published by the International Atomic Energy Agency (IAEA, 1973).

In the first four tests, the same package must be tested in sequence and in the orientation expected to cause the most damage. The extent to which a cask survives such a test is measured by prescribed allowable leak rates and prescribed maximum exposure rates at specified distances from the surface of the package. Regulations, detailed descriptions, leak rates, and survival criteria can be found in 10 CFR 71.51(a)(2), in DOE Order 5480.1, in an NRC regulatory guide (NRC, 1975), and in a standard issued by the American National Standards Institute (ANSI, 1977).

Once a package design to be used for shipments to a repository (not all radioactive-material packages must survive accident conditions) has been demonstrated to survive the rigorous accident conditions as well as many other criteria, a certificate of compliance is issued. The certificate specifies the operating conditions under which the package may be used.

Both the regulations and the certificates can be modified to include experience that relates to the performance of packages. For example, in a recent occurrence (Klingensmith et al., 1980), damaged spent fuel became oxidized during shipment, and a serious contamination problem resulted during unloading. As a result, the NRC has modified the certificates of compliance

of currently certified spent-fuel casks to require that they be operated with inert atmospheres in the cask cavity. By using an inert gas in the cask cavity, the potential for fuel oxidation is substantially reduced.

Since the transportation packaging can be relied on for protecting the public during an accident, shipments can be allowed to occur in general commerce. Consequently, relatively few Federal regulations for vehicles are imposed on the carriers of radioactive materials (excluding physical protection requirements) beyond those required for the carrier of any hazardous material. Vehicle-safety conditions are addressed by other Federal and State regulations that are not specific to vehicles carrying radioactive material. For example, truck safety is governed by the Bureau of Motor Carrier Safety (49 CFR Parts 390-398), which imposes vehicle-safety and driver standards on all interstate truck carriers. Along with other functions, the Bureau conducts unannounced roadside inspections of truck carriers and drivers. During an inspection, the weight and a variety of safety considerations, including vehicle lights and brakes and driver documents, are checked. For rail shipments, similar inspection criteria and safety requirements have been promulgated by the Federal Railroad Administration in 49 CFR Parts 209-236. Regulations related to hazardous materials transportation by rail are discussed in Section A.13.4.2.

A.6 REGULATIONS RELATED TO SAFEGUARDS

An issue that has caused concern about the public risk due to radioactive-material transportation is the hazard posed by the sabotage of a radioactive-material shipment. One postulated scenario is the destruction of a loaded cask with well-placed explosives. Such an attack would be of particular concern if it were conducted in a densely populated area.

A.6.1 SAFEGUARDS

In June 1979, the NRC published regulations for the protection of commercial-spent-fuel shipments. In 1980, after reviewing public comments and assessing its own experience in administering these regulations, the NRC published amendments to the rule. The NRC further amended the rule in 1982 to include State prenotification requirements. The amended rule is currently in effect as 10 CFR 73.37(a)-(f). These regulations were promulgated to address the issue of safeguarding spent-fuel shipments against acts of terrorism and sabotage, including the possible hijacking and subsequent sabotage of such shipments. Known as physical protection or "safeguard" regulations, these security rules are distinguished from other regulations published by the NRC and other Federal agencies that deal with issues of safety affecting the environment and public health. The safeguard regulations reflected analyses conducted in the mid 1970s. In particular, an NRC-sponsored study (DuCharme et al., 1978) suggested that the sabotage of spent-fuel shipments had the potential for producing serious radiological consequences in areas of high population density. The NRC concluded that to protect public health and to minimize danger to life and property, it was prudent to require that certain safeguard measures be taken to protect spent-fuel shipments until a more

precise and scientific analysis could be performed. The study had been concerned with areas of high population density, but, because of the possibility that shipments could be hijacked in low-population areas and subsequently transported to high-population areas, the requirements applied to all shipments regardless of routing.

The NRC stated in the preamble to the rule change that it had intended the original safeguard rules to be in effect until the results of confirmatory research became available and could be analyzed. The NRC and the DOE responded to this need for more testing by sponsoring separate but coordinated experimental programs. Both programs were designed to yield information about the release of radioactive material from a specified reference sabotage event that was defined in terms of the expertise of the saboteurs, the amount of explosives used, the type of charge employed, and the characteristics of the cask. The NRC-sponsored experiments (Schmidt et al., 1982) used model (small-scale) explosives against simulated casks containing irradiated fuel. The program sponsored by the DOE (Sandoval et al., 1983) included one full-scale and several small-scale experiments.

The results of both of these latter studies showed that the likely release of respirable radioactive particles from sabotage and the resulting consequences of individuals breathing such particles are substantially smaller than the estimates made in the previous NRC-sponsored study that had prompted issuance of the original safeguard regulations. That study had predicted several tens of early fatalities and hundreds of latent-cancer fatalities from sabotage in a densely populated urban area of a truck cask containing three fuel assemblies. The subsequent DOE and NRC-sponsored research predicted no early fatalities and fewer than 15 latent-cancer fatalities for the sabotage of a three-assembly cask in a similarly populated area. These latter consequences would occur only under assumptions that are very favorable to the saboteur. Assumptions concerning the age of the spent fuel (i.e., the cooling period), population density, and the lifetime of respirable particles were all postulated at worst- or near-worst-case levels. When such assumptions are changed to more closely resemble typical or normal transportation situations, the resulting consequences are predicted to decline further.

In June 1984, the NRC published proposed amendments to its existing safeguard regulations and solicited public comment. These amendments take into account the results of the experiments sponsored by the NRC and the DOE, but continue to provide for protection against the loss of control over a shipment and the unhindered movement of the shipment by a saboteur. The objectives of both the current rule and the proposed amendments are to--

1. Deny an adversary easy access to shipment-location information.

2. Provide for early detection of hostile moves against, or the loss of control over, a shipment.

3. Provide a means to quickly summon assistance from local law-enforcement authorities.

4. Provide a means to impede the unauthorized movement of a truck shipment into a heavily populated area.

The current NRC safeguard rule requires--

1. Advance notification of each shipment to the NRC.

2. Maintenance of a communications center to continuously monitor the progress of each shipment.

3. Keeping a written log describing the shipment and significant events during the shipment.

4. Advance arrangements with local law-enforcement agencies along the route.

5. Advance route approval by the NRC.

6. Avoiding scheduled intermediate stops to the extent practicable.

7. At least one escort to maintain visual surveillance of the shipment during stops.

8. Shipment escorts to contact the communications center every 2 hours to report the status of the shipment.

9. Capability to immobilize the cab or cargo-carrying portion of a shipment transported by truck.

10. Armed escorts in heavily populated areas.

11. On-board communications equipment.

12. Advance notification to the governor of a State (or the governor's designee) of a shipment to be transported within or through his State, giving the estimated date and time of entry into the State and applicable routing information. This information must not be publicly released until 10 days after the shipment has entered or originated within the State.

All of these requirements will continue to be in effect for shipments of spent nuclear fuel that has been cooled less than 150 days because there is currently not enough information on the consequences of sabotage to this "hotter" fuel to warrant regulatory modifications.

The proposed amendments change the regulations for shipments of spent fuel cooled 150 days or more by eliminating the requirements for--

1. Maintenance of a communications center.
2. Written logs.
3. Advance arrangement with local law-enforcement agencies.
4. Contacts every 2 hours by escorts.
5. Armed escorts in cities.
6. Advance route approval by the NRC.

At present, NRC's safeguard rules apply only to NRC licensees. However, DOT regulations require that DOE-owned spent fuel be shipped under a physical-protection plan that is equivalent to NRC safeguard rules and has been approved by DOT (49 CFR 173.22(c)). DOE Order 1540.1, which covers DOE transportation regulations, is being revised and will include physical protection procedures that essentially parallel the physical-protection procedures proposed by the NRC in 1984.

When shipping commercial waste to a repository, the OCRWM will comply with whatever NRC shipment-protection requirements are in force at the time. The NRC safeguard requirements at present are limited to spent-fuel shipments. The OCRWM will work with the NRC to establish the need for, and the function of, safeguard requirements for the other radioactive waste that could be shipped under the Act.

A.6.2 CONCLUSION

Though transportation packagings have not been specifically designed to mitigate the consequences of a sabotage event, they have been shown experimentally to limit to low levels the potential adverse health consequences to the public. Predictions based on releases experimentally determined in both DOE and NRC studies indicate that no immediate radiation-induced deaths and a small number of latent-cancer fatalities would be expected even in a very densely populated area (Sandoval et al., 1983). To create the level of hazard encountered in the experiments, such sabotage attempts would have to be performed by trained experts, and precise placement of the explosives in the most vulnerable positions would be necessary.

In order to protect the health and safety of the public, the packaging of shipments made to a repository will be as strong as those used in the experimental studies.

A.7 PACKAGINGS

This section discusses the design and fabrication of transportation packagings, trends in future designs, the designs assumed for the cost and risk analysis, and possible future developments.

A.7.1 PACKAGING DESIGN, TESTING, AND ANALYSIS

Radioactive-material packagings, or casks, are designed and certified to carry specific contents. This is necessary because of the unique thermal, radiological, and criticality characteristics of the contents. Other materials can be carried in the cask only if it can be shown that they present no greater radiological, thermal, or criticality hazards than those of the certified contents. Several cask types will be used for transporting waste to a repository. Generally, the size of the package will be dictated by the mode of transportation.

The type of packaging to be used for shipments to a repository is required to survive the conditions of both normal transportation and accidents. Survival is determined by the extent to which the packaging contains its contents, shields against excessive levels of radiation, and prevents a nuclear chain reaction from occurring even after being subjected to the prescribed hypothetical accident conditions (see Section A.5).

A new packaging is designed through a rigorous process similar to that for other nuclear-related products. If a feasible design is proposed, the design proceeds through an engineering analysis of its survivability when subjected to the testing conditions. Physical engineering tests may be conducted during this stage to support analyses. Proof of survivability under accident conditions is required either through analysis, full-scale or model testing, or a combination of both. Once feasibility and survivability are ensured, a final design is prepared. In the design of packaging used for commerical-waste shipments to a repository, all of this effort will be performed by the cask designer for the DOE under a rigorous quality-assurance program. Once the DOE is certain that the design satisfies all requirements, a safety-analysis report for packaging (SARP) will be submitted to the NRC. This SARP will contain a description of all analyses and will be the means for transmitting all operational and safety information to the reviewer. Once the NRC is convinced that all criteria have been satisfied, it will issue a certificate of compliance.

Since packaging certification can be based on engineering analysis, without actual physical testing, it is important to have confidence that the analytical results closely represent those that might be expected to occur if a package were actually subjected to accident conditions. Several experimental programs, both reduced-scale and full-scale, have been run to produce carefully controlled accident environments that can be directly correlated with analysis (Jefferson and Yoshimura, 1978). The correlations have been reasonably close, and much confidence has been developed in analytical modeling capabilities as a reliable and cost-effective tool to replicate response to accident conditions.

A.7.2 TYPES OF PACKAGING

The analyses presented for transportation in this environmental assessment are based on the representative characteristics of a new family of casks that are expected to be used to transport spent fuel and high-level waste. These casks either are being designed now or will be designed in the future, and more accurately represent the type of packaging that will be used than do existing casks being used to transport commercial spent fuel.

As stated earlier, packagings are designed for specific contents; spent-fuel casks are no exception. The existing casks that are currently in use are designed to shield, dissipate heat, and prevent a nuclear chain reaction in spent fuel that has just come out of a reactor. Because the spent fuel to be shipped to a repository will have been out of the reactor for many years (5 years at a minimum), the existing casks are "overdesigned" for the mission. Although the expected radiation-dose rates would be much lower than those allowed by regulation, the cask payloads are also lower than optimum, thus requiring more shipments. The lower radiological risk per shipment using

existing casks would be roughly offset by the increased overall risk that would result from the increased number of required shipments.

The DOE is planning new cask designs that will increase payloads and substantially reduce the number of shipments. Table A-1 presents the cask capacities assumed for performing the consequence and risk analyses in Section A.8. These casks will benefit from past designs, but the application of current technology and analytical tools may allow improvements in design. For example, new-generation casks will probably be designed to be handled entirely remotely and thus will eliminate much routine worker exposure.

A.7.2.1 Spent-fuel casks

Figures A-1 and A-2 show a representative truck cask and a representative rail cask that will be used to transport spent fuel to a repository or to a facility for monitored retrievable storage (MRS) if such a facility is approved by Congress (see Section A.8.3.4). The 100-ton rail cask depicted could also be used for barge transport. The truck cask will be able to accommodate two spent-fuel assemblies from a pressurized-water reactor (PWR) or five assemblies from a boiling-water reactor (BWR). This represents about a doubling of capacity over existing truck casks. The representative truck cask will weigh 21,773 kilograms (48,000 pounds) when empty; when the cask is loaded on the tractor and trailer, the vehicle will weigh less than 36,288 kilograms (80,000 pounds), a weight that will allow it to travel relatively unimpeded by State weight limits for vehicles on the nation's highways. The cask may be constructed of carbon or stainless steel; shielding may be provided by steel, depleted uranium, or lead.

The rail/barge cask will be able to accommodate 14 PWR or 36 BWR assemblies, again representing a doubling of current cask capacity. The concept shown has a stainless-steel body with a sufficient wall thickness to meet all structural and radiation-limit requirements of regulations.

The conceptual designs for both the truck and the rail/barge casks have external impact limiters (shock absorbers designed to reduce the effects of accidents) mounted on the casks, as well as internal impact limiters made of crushable honeycomb material.

A.7.2.2 Casks for defense and commercial high-level waste

An artist's concept of the truck cask for defense high-level waste (DLHW) is shown in Figure A-3. It will be able to carry one 0.6- by 3-meter (2- by 10-foot) canister of vitrified defense waste (and possibly commerical high-level waste from the West Valley Demonstration Project (WVHLW)). When the cask is loaded on the tractor and trailer, the loaded trailer and tractor will weigh less than 36,288 kilograms (80,000 pounds). The cask will be constructed of stainless steel and will have a shielding sleeve of depleted uranium and steel. The cask will have features that allow it to be remotely handled, and the impact limiters will not have to be removed during loading

Table A-1. Reference cask capacities

Origin and destination	Waste type[a]	Container	Capacity[b]
	SPENT FUEL AND SECONDARY WASTE		
From reactors to repository or MRS facility			
Truck	Spent fuel	Unconsolidated assemblies	2/5
Rail	Spent fuel	Unconsolidated assemblies	14/36
From MRS facility to repository, 100-ton casks			
Salt sites	Spent fuel	Disposal container[c]	24/30
Tuff site	Spent fuel	Disposal container[c]	18/42
Basalt site	Spent fuel	Disposal container[c]	24/45
From MRS facility to repository, 150-ton casks			
Salt sites	Spent fuel	Canister[d]	72/150
Tuff site	Spent fuel	Canister[d]	48/98
Basalt site	Spent fuel	Canister[d]	84/171
From MRS facility to all sites			
100-ton casks	Hardware and high-activity low-level waste	Canister[e]	4
150-ton casks	Hardware and high-activity low-level waste	Canister[e]	7
Rail	Contact-handled transuranic waste	Drum	(f)
	HIGH-LEVEL WASTE		
Defense waste			
Truck	Glass HLW	Canister	1
Rail	Glass HLW	Canister	5
Commercial waste[g]			
Truck	Glass HLW	Canister	1
Rail	Glass HLW	Canister	7

[a] PWR = pressurized-water reactor; BWR = boiling-water reactor.
[b] Pairs of numbers show the number of PWR and BWR assemblies, respectively; for example, 2/5 means 2 PWR assemblies or 5 BWR assemblies.
[c] Disposal containers suitable for direct emplacement in a repository. Container sizes are different for each repository host rock.
[d] In thin-wall canisters that would require encapsulation in disposal container at the repository. Canister sizes are different for each repository host rock.
[e] A canister contains five 55-gallon drums.
[f] Thirty-six drums per transport package, two packages per railcar.
[g] High-level waste from the West Valley Demonstration Project.

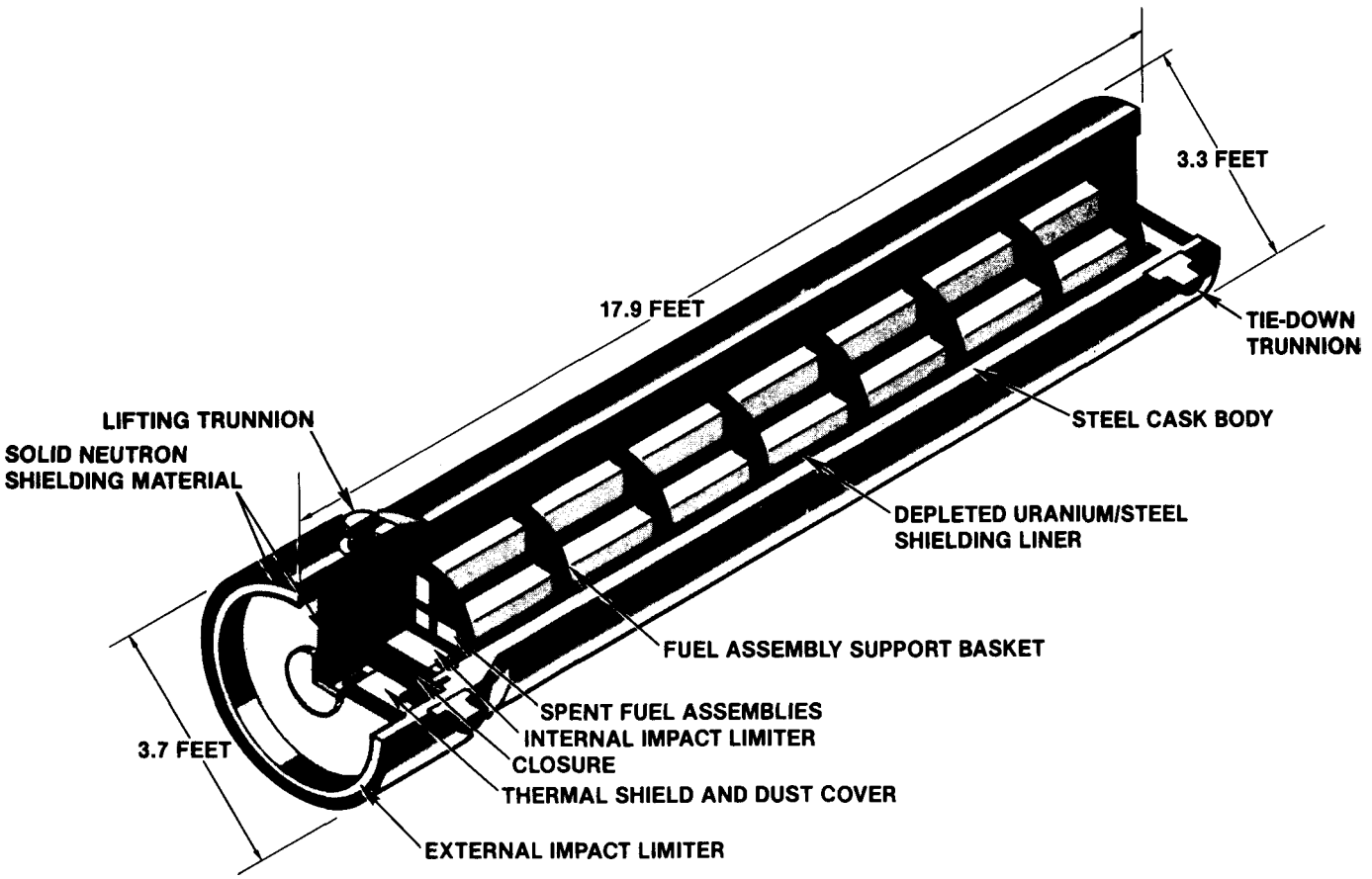

Figure A-1. Truck spent fuel cask.

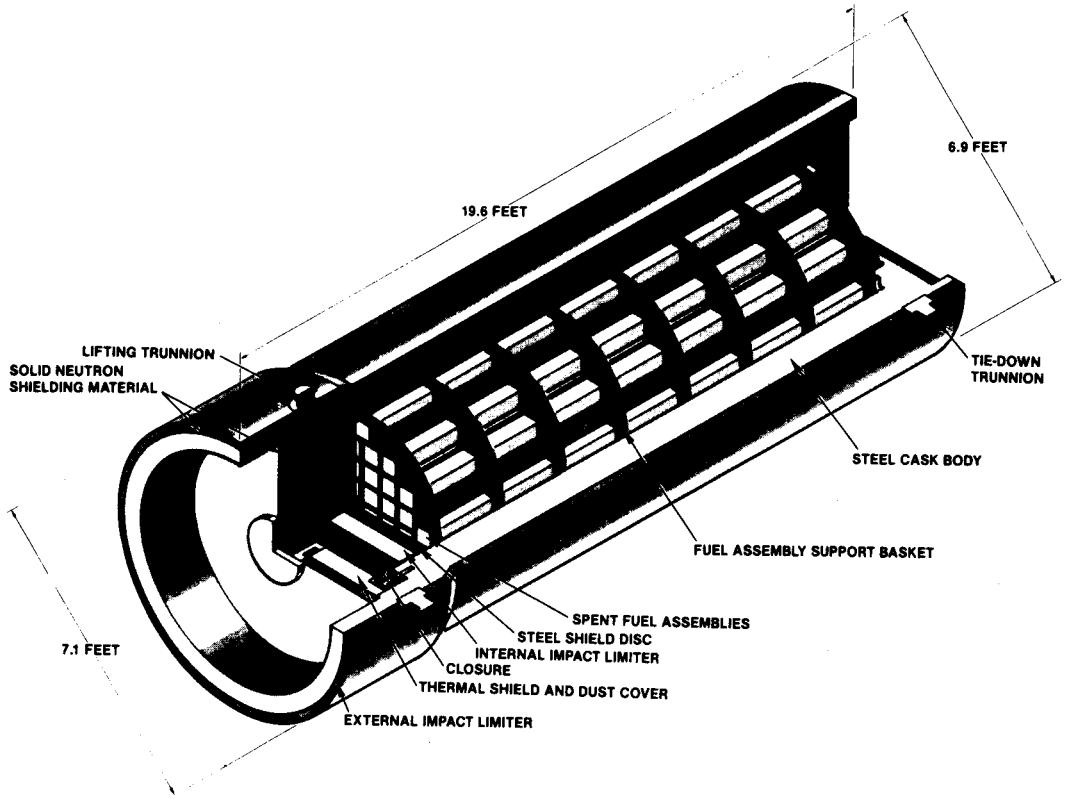

Figure A-2. Rail/barge spent fuel cask.

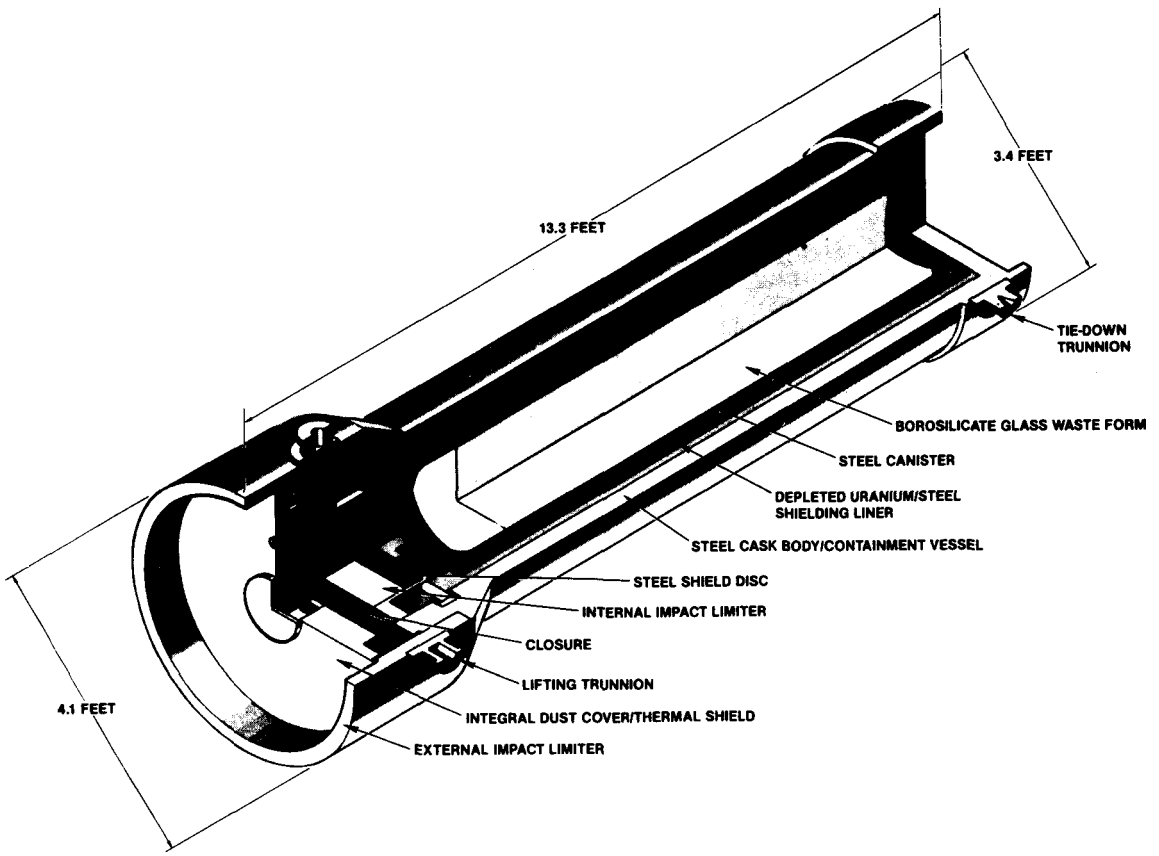

Figure A-3. DHLW truck cask.

and unloading. A rail cask may also be developed; and its capacity is expected to be five canisters of vitrified defense high-level waste (see Table A-1.)

A.7.2.3 Casks for use from an MRS facility to the repository

The DOE's Mission Plan (DOE, 1985) discusses an improved-performance waste-management system that includes a facility for monitored retrievable storage (MRS). Fully integrated into the system, the MRS facility would perform most of the waste-preparation functions now assigned to the repository. In particular, it would consolidate the spent-fuel rods, which are contained in rectangular spent-fuel assemblies, into a tighter circular array, load the consolidated rods into a metal canister, and store the canister until shipment to a repository, where the canisters would be encapsulated in disposal containers and emplaced in the underground disposal rooms. It would also be possible to have the MRS load the consolidated-fuel canisters into disposal containers, which would require no further preparation at the repository.

Casks that would be used in transporting the consolidated spent fuel from the MRS facility to the repository have not yet been designed; however, any design would be certified by the NRC. Scoping analyses have been completed and allow projections of cask capacities to be made. These projections are presented in Table A-1 for casks that weigh 100 and 150 tons. The larger cask may be feasible if an MRS facility is approved by Congress. The cask capacities depend on the host rock of the repository because each host rock is assumed to require a unique canister design and size.

The consolidation of spent-fuel rods at an MRS facility would separate the fuel from the structural components and therefore create another waste type that requires disposal. This secondary waste is separated into three classes: hardware, high-activity low-level waste (HAW), and contact-handled transuranic waste (CH-TRU). It is assumed that the hardware and high-activity waste would be loaded into 55-gallon drums, with five drums loaded into a canister. Packaging capacities for these wastes are given in Table A-1. The transuranic waste would be loaded into 55-gallon drums and shipped in a packaging that is assumed to have a capacity of 36 drums. Two of these packages could be carried by a railcar while only one could be carried by a truck trailer.

A.7.3 POSSIBLE FUTURE DEVELOPMENTS

A.7.3.1 Mode-specific regulations

Even with the safety record of packagings that have been analyzed or tested to survive accident conditions, the NRC is currently reviewing regulations defining accident test conditions in order to assess whether the conditions sufficiently bound those experienced in real accidents. The regulations prescribing accident conditions for transportation are not specific to the mode of transportation, the implicit assumption being that the conditions for all modes are covered by the current standards. Such an

assumption has been questioned, and, in response, the NRC is comparing the current standards with actual accident experience for all modes.

A.7.3.2 Overweight truck casks

Highway load restrictions limit the weight of truck casks, which in turn limits cask payloads. In general, these limitations are intended to protect the nation's highway system from damage. Considering the safety objective of minimizing the number of spent-fuel shipments, however, the DOE, in approving designs for future casks, will balance the benefit of reducing shipments against possible road damage caused by overweight vehicles.

Slightly larger truck casks can increase payload capacity, which, in turn, can significantly reduce the number of shipments. The DOE intends to investigate the potential of these larger casks and will consider their use if additional road damage can be minimized. The proposed use of any overweight equipment will be subject to early review and comment by appropriate State officials because the DOE recognizes the State as the permit-issuing authority for shipments requiring overweight or oversize equipment over the nation's highway system.

A.7.3.3 Rod consolidation

Another way to increase the capacities of spent-fuel casks is to consolidate spent-fuel rods in a canister, as mentioned above for the MRS facility. By so doing, cask capacities might be doubled. Preliminary investigations indicate that, in terms of cask design, the principal problems associated with rod consolidation are the increase in weight and the amount of heat that must be dissipated.

A.7.3.4 Advanced handling concepts

Since the number of radioactive-material packages received and handled at a repository will be high, even the low levels of radiation at the surfaces of the packages would be sufficient to cause high total worker exposure. In an attempt to minimize worker exposure, the use of advanced remote-handling equipment, such as robotics, for unloading the packages is being investigated. New shipping casks will be designed to facilitate the cask handling and unloading operations at the repository or MRS facility.

A.7.4 CONCLUSIONS

The design and performance of current packagings are adequate for the specific contents for which they were designed. However, the waste to be transported to a repository would not be efficiently transported in existing casks since it is older and cooler than the contents for which the existing casks were designed (typically spent fuel cooled for 180 days). Therefore, new casks designed for fuel at least 5 years old will be added to the fleet.

These casks will have increased capacities and features that facilitate remote handling. Because these new casks more realistically represent future shipping operations, the expected characteristics of these casks are used in this environmental assessment.

A.8 POTENTIAL HAZARDS OF TRANSPORTATION

This section provides a numerical estimate of the hazard associated with transporting radioactive waste to a repository. In response to numerous comments received on the draft Appendix A, additional emphasis was placed on the potential consequences to an individual, as opposed to a general population. The goal was to answer the frequent question: "What happens to me, if ...?" After explaining the consequences that could be experienced by an individual affected to a credible maximum extent, the consequences are extrapolated to a general population and then finally are combined with accident probabilities to produce an expected value of risk to the public. A separate analysis was performed to consider barge transport, which currently is thought only to provide a potential supplementary role in the transportation system (see to Section A.10). The potential uncertainties inherent in the results presented here are also discussed.

It must be emphasized at this juncture that all analyses are thought to be conservative, and hence the risks they predict are expected to be much greater than the risk that may actually occur.

A.8.1 POTENTIAL CONSEQUENCES TO AN INDIVIDUAL EXPOSED TO THE MAXIMUM EXTENT

The analyses in this section are really ("snapshots in time") where an individual is exposed as a result of a particular set of circumstances that may never happen and would probably never happen twice in exactly the same way or to the same individual. These analyses are specific to a single shipment, and details about shipping schedules and scenarios are deferred until Section A.8.2.

A.8.1.1 Normal transportation

This section presents estimates of credible maximum radiation doses that may be received by a person from selected activities that could result from transportation operations. The activities are not related to accidents but rather could occur during normal operations.

The results in the tables are taken from Sandquist et al. (1985). Sandquist et. al. represent truck and rail casks with a simple analytical model and assume that the dose rates emitted from the casks are at regulatory levels (i.e., at the maximum levels permitted by existing regulations). Table A-2 presents estimates for a truck cask, and Table A-3 is for a rail cask. A number of services or activities are analyzed for each mode.

In order to explain what the results in the tables mean, consider Table A-2 for truck. Under the "truck servicing" category, the table gives the dose

Table A-2. Projected maximum individual exposures from normal transport (truck spent-fuel cask)[a]

Description (service or activity)	Mean distance to center of cask (ft)	Maximum exposure time (min)	Dose rate and total dose
Caravan			
Passengers in vehicles traveling in adjacent lanes in the same direction as cask vehicle	35	30	0.04 mrem/min 1 mrem
Traffic obstruction			
Passengers in stopped vehicles in lanes adjacent to the cask vehicle; vehicles have stopped because of traffic obstruction	15	30	0.1 mrem/min 3 mrem
Residents and pedestrians			
Slow transit (because of traffic control through area with pedestrians)	20	6	0.07 mrem/min 0.4 mrem
Truck stop for driver's rest; exposures to residents and passers-by	130	[b]	0.006 mrem/min 3 mrem
Slow transit through area with residents (homes, businesses, etc.)	50	6	0.02 mrem/min 0.1 mrem
Truck servicing			
Refueling (100-gallon capacity)			0.06 mrem/min
One nozzle from one pump	25 (at tank)	40	2 mrem
Two nozzles from one pump	25 (at tank)	20	1 mrem
Load inspection and enforcement	10[c]	12	0.2 mrem/min 2 mrem
Tire change or repair of cask trailer	16[d]	50	0.1 mrem/min 5 mrem
State weight scales	15	2	0.1 mrem/min 0.2 mrem

[a] These exposures should not be multiplied by the expected number of shipments to a repository in an attempt to calculate a worst case because the same individual would not be exposed for every shipment, nor would these circumstances arise during every shipment. An individual residing 100 feet from a transportation route and witnessing every shipment would receive an annual dose of 2 to 8 mrem, depending on the mode of shipment and the cask size.

[b] Assumed to be overnight (8 hours).

[c] Inspection occurs near personnel barrier.

[d] Changed tire is the inside tire nearest cask.

Table A-3. Projected maximum individual exposures from normal transport (rail spent-fuel cask)[a]

Description (service or activity)	Mean distance to center of cask (ft)	Maximum exposure time (min)	Dose rate and total dose
Caravan			
Passengers in rail cars or highway vehicles traveling in same direction and vicinity as cask vehicle	65	10	0.03 mrem/min 0.3 mrem
Traffic obstruction			
Persons in vicinity of cask vehicle stopped or slowed down by rail traffic obstruction	20	25	0.1 mrem/min 2 mrem
Residents and pedestrians			
Slow transit (through station or because of traffic control) through area with pedestrians	25	10	0.07 mrem/min 0.7 mrem
Slow transit through area with residents (homes, businesses, etc.)	70	10	0.02 mrem/min 0.2 mrem
Train stop for crew's personal needs (food, crew change, first aid, etc.)	150	120	0.005 mrem/min 0.7 mrem
Train servicing			
Engine refueling, car changes, train maintenance, etc.	35	120	0.04 mrem/min 5 mrem
Cask inspection and enforcement by train, State, or Federal officials	10	10	0.2 mrem/min 2 mrem
Cask-car coupler inspection or maintenance	30	20	0.07 mrem/min 1 mrem
Axle, wheel, or brake inspection, lubrication, or maintenance on cask car	25	30	0.09 mrem/min 3 mrem

[a] These exposures should not be multipled by the expected number of shipments to a repository in an attempt to calculate a worst case because the same individual would not be exposed for every shipment, nor would these circumstances arise during every shipment. An individual residing 100 feet from a transportation route and witnessing every shipment would receive an annual dose of 2 to 8 mrem, depending on the mode of shipment and the cask size.

delivered to a person changing a tire on the trailer of a truck carrying a loaded spent-fuel cask. To change the tire, that required him to be only 5 meters (16 feet) from the center of the cask. It was further assumed that changing the innermost tire (dual wheels) would take almost a full hour. The dose rate at the location was estimated to be 0.1 millirem (mrem) per minute, a rate that would produce a 5-mrem dose to an individual for the complete service procedure. This dose is about the same as that received on a transcontinental airplane trip. If this person were estimated to change many tires in a year, the DOE may impose administrative controls to minimize the accumulated dose. Such control could be something as simple as requiring temporary lead shields between the cask and the area where the tire was to be changed.

Many of the services or activities analyzed would require administrative controls if they were to happen routinely. Routine occurrences either would not be allowed, or administrative controls would be applied to limit cumulative exposures. These types of activities and services will be more fully analyzed during the preparation of the environmental impact statement. This analysis does highlight the fact that additional controls may be necessary for the large numbers of shipments that will occur under the Act, but it must also be emphasized that the simplified model used by Sandquist et al. (1985) will calculate doses much greater than expected.

A.8.1.2 Accidents

Table A-4 presents the results of an analysis performed by Sandquist et al. (1985) to evaluate the individual dose that may result from three classes of very severe accidents--accidents that would produce conditions more severe than the regulatory test conditions. Accidents of this severity are not likely to occur during shipments to a repository.

Each set of results in Table A-4 is for an accident in which there is a release from a rail cask carrying 14 PWR assemblies. The releases are consistent with those assumed in past analyses (Wilmot et al., 1983; Neuhauser et al., 1984) and are based on the release mechanisms defined by Wilmot (1981).

The three accident classes (4, 5, and 6) are taken from Wilmot et al. (1983). These are very severe accidents, all of which would produce conditions greatly exceeding those specified in the NRC regulations. A Class 4 accident would require a very severe impact (i.e., perhaps a 30-meter (100-foot) drop onto a granite slab). This impact would release adhered activation products and may rupture a few spent-fuel rods. A Class 5 accident requires a Class 4 impact with a subsequent very intense fire (a fire longer and hotter than that of the regulatory test). A Class 6 accident requires a Class 4 impact and an even hotter fire than Class 5. A Class 6 accident would result in the severe oxidation of ruptured fuel rods. These accidents are extremely unlikely; they are estimated to occur once in a million vehicle accidents.

The maximum dose received by an individual in the most severe accident is about 10,000 mrem; it would be incurred by a person standing about 70 meters (230 feet) from the scene of the accident. Most of the dose comes from

Table A-4. Estimated maximum individual radiation dose for rail-cask accidents

Accident class[c]	Dose (mrem)[a,b]				
	Inhalation	Plume gamma	Ground gamma	Dust inhalation	Total
4	180	11	12	0.0001	200
5	6,100	71	91	0.004	6,300
6	9,000	550	710	0.0006	10,300

[a] Maximum individual dose occurs about 70 meters (230 feet) downwind of the release point.

[b] Values reported as the effective whole-body dose.

[c] Accident class as defined by Wilmot et al. (1983). Class 6 is the most severe, but all classes have probabilities of less than 1 in a million accidents.

inhaling radionuclides from the plume. The dose itself would occur over decades and would come from radionuclides retained within the body. Even if all of the dose were received during a short ("acute exposure") period, the individual would show no symptoms nor have his life threatened. An "acute" dose of about 50,000 mrem would be required before any symptoms would be observable; a dose of more than 450,000 mrem would be required before the chance of dying within 30 days is 50-50 (NCRP, 1962).

The doses calculated can be greater or smaller, depending on the circumstances; however, the analyses made no attempt to account for the mitigating measures that would immediately be exercised after an accident. Even such simple measures as staying indoors could easily reduce the doses by tenfold or more. By carefully tracking the release of material as it is dispersed by the wind, such advisories can be made.

The dose received by a firefighter was calculated for an accident even if no radioactive material was released. If the firefighter spent an hour at the scene of the accident, he would receive a dose of up to 24 mrem. A description of this analysis is also given by Sandquist et al. (1985). If a firefighter was responding to an accident in which there was a release and did not use breathing protection, he could be expected to receive a dose of about 10,000 mrem, as described above for the maximumally exposed individual. With breathing protection, the dose could easily be reduced to less than 1,000 mrem.

A.8.2 CONSEQUENCES TO A LARGE POPULATION FROM VERY SEVERE TRANSPORTATION ACCIDENTS

In this section, some doses are calculated for a large population, not just for a single individual as in Section A.8.1. The accidents analyzed are very unlikely, on the order of 1 in a million accidents or less.

Two scenarios are postulated: (1) an accident where material is released during an accident, dispersed, and deposited on the ground and (2) an accident where the radionuclides released are deposited in a reservoir that is used for many purposes, including drinking water. The three most-severe accident classes defined by Wilmot et. al. (1983) are considered, as described in Section A.8.1.2. Three exposure pathways are considered: inhalation, cloudshine, and groundshine. A fourth, the inhalation of resuspended dust, was found to be unimportant in comparison with the other three. As shown in Table A-5, in the most-severe accident in an urban area, 22 latent-cancer fatalities are predicted for the ground-deposition case and 13 for the water-deposition case. These values are based on the assumption that no mitigating administrative control or accident-scene clean-up takes place. Evacuation would reduce these numbers, as would cleaning up the contaminated areas. In the water-deposition case, no credit was taken for the normal settling and filtering processes that take place during water treatment and would certainly be employed after an accident. Details can be found in the report by Sandquist et al. (1985).

Table A-5. Estimated 50-year population dose for rail-cask accidents[A]

Accident consequence	Air release[B]								Water release in urban area[E]
	Urban area[C]				Rural area[D]				
	Inhalation	Plume gamma	Ground gamma	Total	Inhalation	Plume gamma	Ground gamma	Total	
CLASS 4 ACCIDENTS[F]									
Population dose (man-rem)	3	0.33	940	940	0.005	0.0005	1.4	1.4	180
Number of latent-cancer fatalities[G]				0.2				0.0003	0.04
CLASS 5 ACCIDENTS[F]									
Population dose (man-rem)	110	2.2	13,000	13,000	0.2	0.003	21	21	6,900
Number of latent-cancer fatalities[G]				3				0.004	1.4
CLASS 6 ACCIDENTS									
Population dose (man-rem)	150	17	110,000	110,000	0.2	0.03	170	170	63,000
Number of latent-cancer fatalities[G]				22				0.04	13

[A] Estimates based on the assumption that there is no cleanup of deposited radionuclides.

[B] The ground dose is the dose that would be received if each member of the population stayed at the same location for 50 years. The inhalation dose is a 50-year dose commitment from the inhalation of the passing plume. Doses are for the population within 80 kilometers (50 miles) of the release point.

[C] Urban area assumed to have 10,000 people per square mile.

[D] Rural area assumed to have 16 people per square mile.

[E] Population dose from water ingestion. The noble gas krypton-85 is omitted because of its negligible uptake by a surface-water body. Population-dose estimates based on a 100-acre, 1-billion-gallon reservoir that supplies the domestic, agricultural, and industrial needs of 37 million people. No radioactive decay, settling, or filtration is assumed. The water-release accident is much less likely to occur than either of the air-release accidents.

[F] Accident classes as defined by Wilmot et al. (1983).

[G] Based on 1 man-rem = 2×10^{-4} latent-cancer fatality plus first- and second-generation genetic effects.

A.8.3 RISK ASSESSMENT

The preceding section presented the consequences of an accident to a large population. This section examines the expected risk to the public (as a group of individuals) by including not only the consequences but also the probability of the accident. The results depend on shipment logistics and schedules for all shipments. In order to describe the results more clearly and to explain the differences between the results presented in the draft appendix and in this final version, this section briefly describes the computational models and the revisions made in the models, the waste-management scenarios that were analyzed, and assumptions about the waste.

A.8.3.1 Outline of method for estimating population risks

By recognizing similarities and uniformities over a national or large regional scale, simplifying assumptions were made in the risk-assessment calculations. Such simplification is justified because the importance of the results presented is not so much in their absolute values but rather in their relative magnitude when compared among the potential repository sites.

The most important simplification was to create "unit-risk" factors, which represent the risk of transportation for a unit distance of travel in a defined population zone. The use and development of unit-risk factors have been described by Madsen et al. (1983).

Once the unit-risk factors have been obtained for the population zones required (in this analysis, three different population densities were considered), three other factors are needed to evaluate the total risk of transportation to a site: (1) the total distance per trip, (2) the fraction of travel in each of the population zones, and (3) the number of shipments that may occur. Actual distances for representative routes were calculated from each reactor and waste source to the potential repository sites. The number of shipments was calculated from detailed logistics models that are best described in the detailed text of Shay et al. (1985). How the fraction of travel in the various population zones was determined is discussed by Cashwell et al. (1985). It is sufficient here to mention that actual 1980 census data were reduced to population contours, which in turn were overlaid on postulated routes. The distance of travel in each zone was subsequently translated to a fraction of travel.

A.8.3.2 Computational models and methods for estimating population risks

The analytical tools (i.e., the analytical models or codes used in this analysis) have been extensively documented elsewhere, and the interested reader is encouraged to review this documentation for details of model development (AEC, 1972; NRC, 1977; Taylor and Daniel, 1977, 1982; Madsen et al., 1983; Wilmot et al., 1983; Neuhauser et al., 1984). This section identifies the models and shows that they have been developed, used, and verified sufficiently to establish their credibility.

The RADTRAN-II code, which was used to calculate the radiological unit-risk factors, is the product of about 10 years of development. Its precursor was used to produce the environmental assessment used in Interstate Commerce Commission (ICC) hearings concerning the issue of hauling radioactive material in trains dedicated to radioactive material (ICC, 1977). RADTRAN was used to produce documents that are current standards for evaluating the risk of transporting radioactive materials (NRC, 1977, 1983). Furthermore, the code has been used as the basis for other significant risk-assessment tools, including METRAN (Finley et al., 1980), which evaluates the risk of transportation in urban areas, and INTERTRAN (Ericson and Elert, 1983), which is the risk-assessment tool of the International Atomic Energy Agency.

The nonradiological unit-risk factors were calculated from available data collected from actual transportation records (Cashwell et al., 1985).

HIGHWAY (Joy et al., 1982) and INTERLINE (Peterson, 1984) are routing models for highway and rail shipment. Developed over the past several years, they are updated periodically to reflect current road and track conditions and railroad ownership. They are benchmarked against reported mileages and observations of commercial truck and rail firms.

A.8.3.3 Changes in the analytical models and methods for estimating population risks

Many significant improvements have been made in the analytical models and methods since the analyses were by completed by Neuhauser et al. (1984), for the draft environmental assessment. A couple of the modifications have resulted in significant changes in the absolute value of the expected results, and therefore it is important to identify them. The interested reader is encouraged to review the references given.

The most important improvement was made to the railstop model in RADTRAN-II, which calculates the occupational and public dose accumulated as a truck or train is stopped during transit. The primary basis for the change is a survey performed by an expert in railroad operations and documented by Ostmeyer (1985a). The railstop-exposure model can treat both general-freight and "dedicated-train" (see Section A.13.4.3) shipments. The model classifies railstop exposures into two types: employee proximity exposures and general rail-and-nonrail population exposures. The proximity exposures are received by employees who handle waste shipments at railstops. In the case of general-freight shipments, these exposures result from train classifications, car repair, and train inspections. The dedicated-train proximity exposures result from train inspections and car repairs. General rail-and-nonrail exposures are received by railyard employees not handling the shipment and the general population that surrounds the railyard. Unlike crew proximity exposures, which depend on the number of train "handlings," general-population exposures depend on railstop duration.

Another major change to RADTRAN II is the addition of a food-ingestion model. Population doses from food ingestion are estimated by using radionuclide transfer fractions. The model is documented by Ostmeyer et al.

(1985b). Population food exposures are estimated only for accidents that occur in rural areas. However, because of the nature of the model, food-ingestion doses are not limited to the residents of rural areas.

Food transfer fractions were determined for cobalt, cesium, strontium, and plutonium radionuclides. All other radionuclides will make negligible contributions to food-pathway risks for waste-transportation accidents. Each transfer fraction represents the "time-integrated" transfer of the radionuclide through the food-ingestion pathway. Transfer fractions were determined by using both empirical fallout data and systems-analysis models.

The occupational and nonoccupational nonradiological risks for rail accidents were updated to be consistent with the most recent edition of National Transportation Statistics (DOT, 1985). In addition, the calculation of risk associated with dedicated trains was updated to incorporate the appropriate statistical base. Two years of accident data, 1982 and 1983, are cited in this document; to obtain statistics for the analysis performed here, the data for both years were averaged.

For calculating all of the radiological and nonradiological risks associated with incident-free rail transportation, input must be in terms of fatalities per railcar-kilometer and injuries per railcar-kilometer. For general-commerce rail transportation, average occupational and nonoccupational accident-related fatalities are divided by the appropriate average values for railcar-kilometers of Class I freight. The number of injuries are derived from the numbers of fatalities.

However, unlike all radiological risks and incident-free nonradiological pollution risks, which depend on train length, the nonradiological-accident term is dominated by grade-crossing accidents, whose occurrence depends solely on the number of trains rather than the length of trains carrying radioactive waste. Consequently, for dedicated trains only, the unit risk factors are expressed in terms of risk per train rather than risk per railcar. Dedicated trains are assumed for shipments from the MRS facility. Further details are given by Cashwell et al. (1985).

Finally, a method was developed for modifying unit-risk factors to reflect changes in population densities. A brief discussion of this method is presented below.

In the relationships given below, five symbols are used. They are defined as follows:

F_1= A zone- and material-dependent risk factor based on rural, suburban, and urban population densities of 6, 719, and 3,861 persons per square kilometer, respectively.

F_2= Any revision to F_1 desired because of a change in population density.

$\S_1$= One of the population densities (6, 719, or 3,861 persons per square kilometer).

$\S_2$= The altered value of a population density.

a= The fraction of the normal nonoccupational radiological risk contributed by offlink exposures to the general population [a = offlink/(onlink + stops + offlink)].

The following values of the quantity a were used for each mode and population zone:

Mode	Rural	Suburban	Urban
Truck	0.00	0.18	0.07
Train	0.03	0.85	0.47
Dedicated Train	0.23	0.97	0.76

The resultant radiological and nonradiological risk factors are as follows:

Radiological Risks

Normal occupational fatalities	Unchanged
Normal nonoccupational fatalities	$F_2 = F_1[a(\S_2/\S_1) + (1 - a)]$
Accident nonoccupational fatalities	$F_2 = (\S_2/\S_1)F_1$

Nonradiological Risks

Normal nonoccupational fatalities	$F_2 = (\S_2/\S_1)F_1$
Accident occupational fatalities	Unchanged
Accident nonoccupational fatalities	Unchanged
Accident injuries	Unchanged

A.8.3.4 Transportation scenarios evaluated for risk analysis

The DOE has described two different waste-management systems in the Mission Plan (DOE, 1985): an authorized system and an improved-performance system. In the authorized system, spent fuel and defense high-level waste would be shipped directly from the sources (reactors and waste sources) to the repository. In the improved-performance system, a centrally located MRS facility would be used to prepare the spent fuel for disposal in the repository.

The rate at which the repository would accept spent fuel and high-level waste is given in Table A-6 for the authorized system. The high-level waste is assumed to be sent directly to the repository under either plan. The volume of defense waste that is used for this analysis is greater than that presented in the Mission Plan in order not to underestimate the environmental impact of transporting this waste.

Several cases are considered for the improved performance system; they are defined by changes to two inputs: (1) the size of the cask used to transport waste to the repository from the MRS facility and (2) the location to which reactors west of the Rocky Mountains (longitude 100°W) ship their spent fuel. Two cask sizes were considered: 100 and 150 tons. Reactors west

Table A-6. Repository waste-acceptance schedule for the authorized system (metric tons of uranium)

Year	Spent fuel	High-level waste[a, b]			
		Savannah River	INEL[c]	Hanford	West Valley[d]
1998	400				
1999	400				
2000	400				
2001	900				
2002	1,800				
2003	3,000	350		75	20
2004	3,000	350		75	20
2005	3,000	350		75	20
2006	3,000	350		75	20
2007	3,000	350		75	20
2008	3,000	200	300	75	20
2009	3,000	200	300	75	20
2010	3,000	200	300	75	20
2011	3,000	200	300	75	20
2012	3,000	200	300	75	20
2013	3,000	200	300	75	20
2014	3,000	200	300	75	20
2015	3,000	200	300	75	20
2016	3,000	350	300	75	20
2017	3,000	350	300	75	20
2018	3,000	350	300		20
2019	3,000	350	300		20
2020	3,000	350	300		20
2021	3,000	350	300		20
2022	1,100	350	300		20

[a] A canister of high-level waste contains the fission products from the reprocessing of 0.5 MTU of spent fuel.

[b] The values given for high-level waste were developed for use in these EAs. They are believed to be maximum values that would not be exceeded and do not reflect expected values. They do not compare with the values given in the Mission Plan (DOE, 1985).

[c] Idaho National Engineering Laboratory.

[d] Commercial high-level waste from the West Valley Demonstration Project.

of longitude 100°W were assumed to ship either directly to the repository or to the MRS facility. All four combinations were considered. The waste-acceptance rates for the MRS facility and the repository are given in Tables A-7 and A-8 for the two cases involving different destinations for the spent fuel from western reactors.

A.8.3.5 Assumption about wastes

Detailed descriptions of the spent fuel and miscellaneous wastes are given by Cashwell et al. (1985); however, some basic assumptions fundamental to the risk analysis are presented here.

The spent fuel was assumed to be 5 years old if shipped from the reactors and 10 years old if shipped from the MRS facility. In order to bound the consequences, all analyses assume that the composition of the radionuclide release during postulated accidents is derived from a pressurized-water reactor. The fuel burnup was assumed to be 33,000 MWd/MTU. It was assumed that the spent-fuel assemblies have limited amounts of radioactivity ("crud") on their exterior surfaces; this can be knocked loose and readily released to the inside of a cask under accident conditions. Spent fuel shipped from the MRS facility is consolidated and shipped either in a thin-wall repository-specific canister or encapsulated in a container designed specifically for disposal in one of the different repository host rocks. (The repository-specific canisters would be encapsulated in disposal containers at the repository.).

The high-level waste--defense high-level waste from three reprocessing plants and commercial high-level waste from West Valley Demonstration Project--was assumed to have the composition of defense waste from the Savannah River Plant. Therefore, each canister of waste was assumed to contain the inventory resulting from the processing of 0.5 MTU of spent fuel. The waste matrix was assumed to be a glass.

The wastes resulting from fuel consolidation--hardware, high-activity low-level waste, and contact-handled transuranic waste (CH-TRU)--were assumed to be shipped along with consolidated spent fuel to the repository. The hardware contains activation products; the high-activity low-level waste also has significant amounts of fission products; and the contact-handled transuranic waste contains mainly transuranic radionuclides, which pose no particular external radiation hazard. The high-activity low-level waste and the hardware are placed in drums and then five drums are loaded into a canister; the transuranic waste is packed in drums.

A.8.3.6 Operational considerations in risk analysis

Shipments from the reactors and HLW processing plants are made by truck or rail in general-commerce shipments. Cask sizes are limited so that no special restrictions are encountered enroute. Shipments from the MRS facility, however, are made in dedicated trains that haul only the radioactive material being shipped to the repository. The reference dedicated train

Table A-7. Receipt rates for scenario involving all reactors shipping to an MRS facility

Year	Spent fuel[a] (MTU)		Secondary waste products to repository		
	All reactors to MRS	MRS to repository	Hardware (canisters)	High-activity waste (canisters)	CH-TRU[b] (drums)
1996	400				
1997	1,800				
1998	3,000	400	35	33	74
1999	3,000	400	35	33	74
2000	3,000	400	35	33	74
2001	3,000	900	79	74	166
2002	3,000	1,800	158	147	331
2003	3,000	3,000	264	246	552
2004	3,000	3,000	264	246	552
2005	3,000	3,000	264	246	552
2006	3,000	3,000	264	246	552
2007	3,000	3,000	264	246	552
2008	3,000	3,000	264	246	552
2009	3,000	3,000	264	246	552
2010	3,000	3,000	264	246	552
2011	3,000	3,000	264	246	552
2012	3,000	3,000	264	246	552
2013	3,000	3,000	264	246	552
2014	3,000	3,000	264	246	552
2015	3,000	3,000	264	246	552
2016	3,000	3,000	264	246	552
2017	2,800	3,000	264	246	552
2018		3,000	264	246	552
2019		3,000	264	246	552
2020		3,000	264	246	552
2021		3,000	264	246	552
2022		1,100	97	90	202

[a] Spent fuel only; high-level waste is assumed to be shipped directly to a repository in the improved-performance system, bypassing the MRS facility (see Table A-6).
[b] Contact-handled transuranic waste.

Table A-8. Facility receipt rates for scenario involving only eastern reactors shipping to an MRS facility

Year	Spent fuel (MTU)			Secondary waste products to repository		
	Eastern reactors to MRS	Western reactors to repository	MRS to repository	Hardware (canisters)	High-activity waste (canisters)	CH-TRU (drums)
1996	370					
1997	1,665					
1998	2,775	30	370	32	31	68
1999	2,775	30	370	32	31	68
2000	2,775	30	370	32	31	68
2001	2,775	67.5	832.5	73	68	154
2002	2,775	135	1,665	146	228	306
2003	2,775	225	2,775	244	228	511
2004	2,775	225	2,775	244	228	511
2005	2,775	225	2,775	244	228	511
2006	2,775	225	2,775	244	228	511
2007	2,775	225	2,775	244	228	511
2008	2,775	225	2,775	244	228	511
2009	2,775	225	2,775	244	228	511
2010	2,775	225	2,775	244	228	511
2011	2,775	225	2,775	244	228	511
2012	2,775	225	2,775	244	228	511
2013	2,775	225	2,775	244	228	511
2014	2,775	225	2,775	244	228	511
2015	2,775	225	2,775	244	228	511
2016	2,590	225	2,775	244	228	511
2017	2,800	225	2,775	244	228	511
2018		225	2,775	244	228	511
2019		225	2,775	244	228	511
2020		225	2,775	244	228	511
2021		225	2,775	244	228	511
2022		82.5	1,017.5	90	83	187

consists of five spent-fuel casks, two hardware casks, two high-activity-waste casks, and one railcar carrying contact-handled transuranic waste. The dedicated train has different operational characteristics than a general-commerce train, and the analyses reflect those differences.

A.8.3.7 Values for factors needed to calculate population risks

As described in Section A.8.3.1, four factors are needed to assess the population risks from waste transportation: unit risk factors, shipment distances, fractions of travel in various population zones, and the number of shipments.

Tables A-9 through A-12 present all of the unit risk factors used in the analyses made for this environmental assessment. Tables A-9 and A-10 give the factors for shipments that originate at the reactors and the HLW processing plants. The unit risk factors are given for truck and rail shipment and for each population zone. All rail factors are for an individual railcar in general commerce. Table A-9 presents estimates of the radiological risks from normal transportation and accidents. The normal risk is subdivided into occupational and nonoccupational categories. The accident risk is not divided by occupational category because potential exposures for each category are similar (see Section A.8.1.2), and the population density used in the calculations can be considered to include both categories. Table A-10 presents estimates of the nonradiological risk.

Tables A-11 and A-12 contain risk factors for shipments that originate at the MRS facility. Separate factors are given for consolidated-fuel shipments in both the 100- and 150-ton casks and for the secondary wastes that are generated in consolidation. All shipments from the MRS facility were assumed to be by dedicated train, and therefore the unit risk factors are for a complete train (i.e., the factors are on a train-mile, rather than a railcar-mile, basis).

Shipment distances are found in Tables A-13 and A-14. Table A-13 gives the distances from a few chosen reactors in different regions of the United States to the MRS facility and each repository site and from the MRS facility to each repository site. A complete listing of reactors can be found in the report by Cashwell et al. (1985). Table A-14 shows the distances from the HLW sites to the various repository sites. A summary of total shipment distances is given in Table A-15 for each transportation scenario evaluated for the authorized system and the improved-performance system. Distances are given for the cases where shipments are made by all truck or all rail. For two of the scenarios estimates are given for each waste type to provide a perspective on the contribution of each.

The fractions of travel in the various population zones are found in Tables A-16 and A-17 for the selected reactors and the HLW processing sites, respectively. Routes from each source are analyzed to determine the approximate amount of travel in each of the population ones. Further details and all remaining reactor data can be found in the report by Cashwell et al. (1985).

Table A-9. Radiological risk factors for shipments from waste sources to a repository or MRS facility[a]

Mode	Zone	Hazard group	Spent fuel[b]	DHLW[c]	WVHLW[d]
Truck	Rural	Normal occupational fatalities	4.70E-09[e]	4.14E-09	4.14E-09
Truck	Rural	Normal nonoccupational fatalities	2.84E-08	2.54E-08	2.54E-08
Truck	Rural	Accident nonoccupational fatalities	3.10E-13	2.56E-13	1.79E-13
Truck	Suburban	Normal occupational fatalities	1.03E-08	9.10E-09	9.10E-09
Truck	Suburban	Normal nonoccupational fatalities	4.36E-08	3.92E-08	3.92E-08
Truck	Suburban	Accident nonoccupational fatalities	7.46E-10	1.08E-10	7.60E-11
Truck	Urban	Normal occupational fatalities	1.72E-08	1.52E-08	1.52E-08
Truck	Urban	Normal nonoccupational fatalities	5.96E-08	5.36E-08	5.36E-08
Truck	Urban	Accident nonoccupational fatalities	1.22E-09	2.16E-10	1.52E-10
Rail	Rural	Normal occupational fatalities	2.14E-09	2.04E-09	1.03E-09
Rail	Rural	Normal nonoccupational fatalities	1.15E-09	1.03E-09	1.03E-09
Rail	Rural	Accident nonoccupational fatalities	1.34E-12	5.56E-13	5.40E-13
Rail	Suburban	Normal occupational fatalities	2.14E-09	2.04E-09	2.04E-09
Rail	Suburban	Normal nonoccupational fatalities	7.70E-09	6.90E-09	6.90E-09
Rail	Suburban	Accident nonoccupational fatalities	2.78E-09	2.72E-10	2.64E-10
Rail	Urban	Normal occupational fatalities	2.14E-09	2.04E-09	2.04E-09
Rail	Urban	Normal nonoccupational fatalities	2.58E-09	2.32E-09	2.32E-09
Rail	Urban	Accident nonoccupational fatalities	6.72E-09	5.08E-09	4.92E-09

[a] Radiological risk factors per kilometer of travel. To convert factors to risk per mile, multiply by 1.609. Based on 1 man-rem = 2 x 10^{-4} latent-cancer fatality plus first- and second-generation genetic effects.

[b] Unit risk factors for general-commerce truck and rail transportation of spent fuel; units are per kilometer for truck and per railcar-kilometer for rail.

[c] Unit risk factors for general-commerce truck and rail transportation of defense high-level wastes; units are per kilometer for truck and per railcar-kilometer for rail.

[d] Unit risk factors for general-commerce truck and rail transportation of commercial high-level waste from West Valley; units are per kilometer for truck and per railcar-kilometer for rail.

[e] 4.70E-09 = 4.7 x 10^{-9}.

Table A-10. Nonradiological risk factors for shipments from waste sources to a repository or MRS facility[a]

Mode	Zone	Hazard group	Spent-fuel[b]	DFHLW[c]	WVHLW[d]
Truck	Rural	Normal nonoccupational fatalities	0.00E+00	0.00E+00	0.00E+00
Truck	Rural	Accident occupational fatalities	1.50E-08[e]	1.50E-08	1.50E-08
Truck	Rural	Accident nonoccupational fatalities	5.30E-08	5.30E-08	5.30E-08
Truck	Rural	Accident occupational injuries	2.80E-08	2.80E-08	2.80E-08
Truck	Rural	Accident nonoccupational injuries	8.00E-07	8.00E-07	8.00E-07
Truck	Suburban	Normal nonoccupational fatalities	0.00E+00	0.00E+00	0.00E+00
Truck	Suburban	Accident occupational fatalities	3.70E-09	3.70E-09	3.70E-09
Truck	Suburban	Accident nonoccupational fatalities	1.30E-08	1.30E-08	1.30E-08
Truck	Suburban	Accident occupational injuries	1.30E-08	1.30E-08	1.30E-08
Truck	Suburban	Accident nonoccupational injuries	3.80E-07	3.80E-07	3.80E-07
Truck	Urban	Normal nonoccupational fatalities	1.00E-07	1.00E-07	1.00E-07
Truck	Urban	Accident occupational fatalities	2.10E-09	2.10E-09	2.10E-09
Truck	Urban	Accident nonoccupational fatalities	7.50E-09	7.50E-09	7.50E-09
Truck	Urban	Accident occupational injuries	1.30E-08	1.30E-08	1.30E-08
Truck	Urban	Accident nonoccupational injuries	3.70E-07	3.70E-07	3.70E-07
Rail	Rural	Normal nonoccupational fatalities	0.00E+00	0.00E+00	0.00E+00
Rail	Rural	Accident occupational fatalities	1.81E-09	1.81E-09	1.81E-09
Rail	Rural	Accident nonoccupational fatalities	2.64E-08	2.64E-08	2.64E-08
Rail	Rural	Accident occupational injuries	2.46E-07	2.46E-07	2.46E-07
Rail	Rural	Accident nonoccupational injuries	5.12E-08	5.12E-08	5.12E-08
Rail	Suburban	Normal nonoccupational fatalities	0.00E+00	0.00E+00	0.00E+00
Rail	Suburban	Accident occupational fatalities	1.81E-09	1.81E-09	1.81E-09
Rail	Suburban	Accident nonoccupational fatalities	2.64E-08	2.64E-08	2.64E-08
Rail	Suburban	Accident occupational injuries	2.46E-07	2.46E-07	2.46E-07
Rail	Suburban	Accident nonoccupational injuries	5.12E-08	5.12E-08	5.12E-08
Rail	Urban	Normal nonoccupational fatalities	1.30E-07	1.30E-07	1.30E-07
Rail	Urban	Accident occupational fatalities	1.81E-09	1.81E-09	1.81E-09
Rail	Urban	Accident nonoccupational fatalities	2.64E-08	2.64E-08	2.64E-08
Rail	Urban	Accident occupational injuries	2.46E-07	2.46E-07	2.46E-07
Rail	Urban	Accident nonoccupational injuries	5.12E-08	5.12E-08	5.12E-08

[a] Nonradiological risk factors per kilometer of travel. To convert factors to risk per mile, multiply by 1.609.

[b] Unit risk factors for general-commerce truck and rail transportation of spent fuel, units are per kilometer for truck, per railcar kilometer for normal rail, and per train-kilometer for rail accidents. (Note: for general-commerce rail, 1 train-kilometer is equivalent to 1 railcar-kilometer.)

[c] Unit risk factors for general-commerce truck and rail transportation of defense high-level waste; units are per kilometer for truck, per railcar-kilometer for normal rail, and per train-kilometer for rail accidents. (Note: For general-commerce rail, 1 train-kilometer is equivalent to 1 railcar-kilometer.)

[d] Unit risk factors for general-commerce truck and rail transportation of commercial high-level waste from West Valley; units are per kilometer for truck, per railcar-kilometer for normal rail, and per train-kilometer for rail accidents. (Note: For general-commerce rail, 1 train-kilometer is equivalent to 1 railcar-kilometer.)

[e] 1.50E-08 = 1.5×10^{-8}.

Table A-11. Radiological risk factors for shipments from MRS facility[A]

Mode	Zone	Hazard group	Consolidated spent fuel: 100-ton cask MRS-salt[B]	100-ton cask MRS-tuff[B]	100-ton cask MRS-basalt[B]	150-ton cask MRS-salt[B]	150-ton cask MRS-tuff[B]	150-ton cask MRS-basalt[B]
Rail	Rural	Normal occupational fatalities	6.68E-10	6.68E-10	6.68E-10	6.68E-10	6.68E-10	6.68E-10
Rail	Rural	Normal nonoccupational fatalities	8.32E-10[C]	8.32E-10	8.32E-10	8.32E-10	8.32E-10	8.32E-10
Rail	Rural	Accident non-occupational fatalities	6.58E-12	4.88E-12	6.56E-12	1.76E-11	1.22E-11	2.02E-11
Rail	Suburban	Normal occupational fatalities	6.68E-10	6.68E-10	6.68E-10	6.68E-10	6.68E-10	6.68E-10
Rail	Suburban	Normal nonoccupational fatalities	3.36E-08	3.36E-08	3.36E-08	3.36E-08	3.36E-08	3.36E-08
Rail	Suburban	Accident nonoccupational fatalities	1.29E-08	9.88E-09	1.29E-08	3.46E-08	2.38E-08	3.94E-08
Rail	Urban	Normal occupational fatalities	6.68E-10	6.68E-10	6.68E-10	6.68E-10	6.68E-10	6.68E-10
Rail	Urban	Normal nonoccupational fatalities	7.98E-09	7.98E-09	7.98E-09	7.98E-09	7.98E-09	7.98E-09
Rail	Urban	Accident nonoccupational fatalities	3.10E-08	2.38E-08	3.10E-08	8.30E-08	5.76E-08	9.50E-08

Mode	Zone	Hazard group	Secondary wastes: 100-ton Cask MRS-HRDWR[D]	100-ton Cask MRS-HAW[E]	100-ton Cask MRS-TRU[F]	150-ton Cask MRS-HRDWR[D]	150-ton Cask MRS-HAW[E]	150-ton Cask MRS-TRU[F]
Rail	Rural	Normal occupational fatalities	2.68E-10	2.68E-10	1.56E-10	2.68E-10	2.68E-10	1.56E-10
Rail	Rural	Normal nonoccupational fatalities	3.34E-10	3.34E-10	2.40E-10	3.34E-10	3.34E-10	2.40E-10
Rail	Rural	Accident nonoccupational fatalities	3.46E-16	2.34E-11	3.28E-17	8.50E-16	3.98E-11	3.28E-17
Rail	Suburban	Normal occupational fatalities	2.68E-10	2.68E-10	1.56E-10	2.68E-10	2.68E-10	1.56E-10
Rail	Suburban	Normal nonoccupational fatalities	1.34E-08	1.34E-08	9.66E-09	1.34E-08	1.34E-08	9.66E-09
Rail	Suburban	Accident nonoccupational fatalities	3.58E-14	2.12E-08	2.28E-14	9.80E-14	3.62E-08	2.28E-14
Rail	Urban	Normal occupational fatalities	2.68E-10	2.68E-10	1.56E-10	2.68E-10	2.68E-10	1.56E-10
Rail	Urban	Normal nonoccupational fatalities	3.20E-09	3.20E-09	2.30E-09	3.20E-09	3.20E-09	2.30E-09
Rail	Urban	Accident nonoccupational fatalities	1.80E-13	3.86E-07	4.18E-13	2.74E-13	6.64E-07	4.18E-13

[A] To convert factors to risk per mile, multiply by 1.609. Based on 1 man-rem = 2×10^{-4} latent-cancer fatality plus first- and second-generation genetic effects.

[B] Unit risk factors for dedicated-rail transportation of consolidated spent fuel packaged for shipment to either a salt repository, a tuff repository, or a basalt repository, expressed as risk per 5 railcar-kilometers.

[C] Unit risk factors for dedicated-rail transportation of the transuranic waste (TRU) generated during spent-fuel consolidation, expressed as risk per 1 railcar-kilometer.

[D] Unit risk factors for dedicated-rail transportation of spent-fuel-assembly hardware expressed as risk per 2 railcar-kilometers; packaging is the same regardless of repository site.

[E] Unit risk factors for dedicated-rail transportation of high-activity low-level waste (HAW) generated during spent-fuel consolidation, expressed as risk per 2 railcar-kilometers; packaging is the same regardless of repository site.

Table A-12. Nonradiological risk factors for shipments from MRS facility[A]

Mode	Zone	Hazard group	Consolidated spent fuel[B]	Secondary waste		
			MRS-repository	MRS-HRDWR[C]	MRS-HAW[D]	MRS-TRU[E]
Rail	Rural	Normal nonoccupational fatalities	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rail	Rural	Accident occupational fatalities	1.27E-07[F]	0.00E+00	0.00E+00	0.00E+00
Rail	Rural	Accident nonoccupational fatalities	1.85E-06	0.00E+00	0.00E+00	0.00E+00
Rail	Rural	Accident occupational injuries	1.74E-05	0.00E+00	0.00E+00	0.00E+00
Rail	Rural	Accident non-occupational injuries	3.60E-06	0.00E+00	0.00E+00	0.00E+00
Rail	Suburban	Normal nonoccupational fatalities	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rail	Suburban	Accident occupational fatalities	1.27E-07	0.00E+00	0.00E+00	0.00E+00
Rail	Suburban	Accident nonoccupational fatalities	1.85E-06	0.00E+00	0.00E+00	0.00E+00
Rail	Suburban	Accident Occupational Injuries	1.74E-05	0.00E+00	0.00E+00	0.00E+00
Rail	Suburban	Accident Non-occupational Injuries	3.60E-06	0.00E+00	0.00E+00	0.00E+00
Rail	Urban	Normal nonoccupational fatalities	6.50E-07	2.60E-07	2.60E-07	1.30E-07
Rail	Urban	Accident occupational fatalities	1.27E-07	0.00E+00	0.00E+00	0.00E+00
Rail	Urban	Accident nonoccupational fatalities	1.85E-06	0.00E+00	0.00E+00	0.00E+00
Rail	Urban	Accident Occupational Injuries	1.74E-05	0.00E+00	0.00E+00	0.00E+00
Rail	Urban	Accident Non-occupational Injuries	3.60E-06	0.00E+00	0.00E+00	0.00E+00

[A] Nonradiological risk factors per kilometer of travel. To convert factors to risk per mile, multiply by 1.609.

[B] Unit risk factors for dedicated-rail transportation of spent fuel in 100- and 150-ton casks to a salt repository, a tuff repository, or a basalt repository; expressed as risk per kilometer for normal transportation and as risk per train-kilometer for accidents.

[C] Unit risk factors for dedicated-rail transportation of spent-fuel-assembly hardware, expressed as risk per railcar-kilometer for normal transportation and as risk per train-kilometer for accidents; packaging is not affected by repository site.

[D] Unit risk factors for dedicated-rail transportation of the high-activity low-level waste (HAW) generated during the consolidation of spent fuel; expressed as risk per railcar-kilometer for normal transportation and as risk per train-kilometer for accidents.

[E] Unit risk factors for dedicated-rail transportation of the contact-handled transuranic waste (TRU) generated during the consolidation of spent fuel; expressed as risk per railcar-kilometer or normal transportation and as risk per train-kilometer for accidents.

Table A-13. Distance per shipment from selected[a] reactors and the MRS facility

Reactor	Distance (miles)					
	Salt			Tuff	Basalt	MRS
	Richton	Deaf Smith	Davis Canyon	(Yucca Mt.)	(Hanford)	(Oak Ridge)
Maine Yankee (Maine)						
Truck	1,570	2,150	2,570	3,040	3,107	1120
Rail	1,920	2,180	2,750	3,270	3,150	1480
Crystal River (Florida)						
Truck	579	1,670	2,310	2,600	2,990	639
Rail	571	1,699	2,450	3,000	3,210	698
Quad-Cities (Illinois)						
Truck	959	1,040	1,300	1,780	1,910	714
Rail	1,080	937	1,480	2,000	1,980	861
Palo Verde (Arizona)						
Truck	1,908	789	509	606	1,550	1920
Rail	1,950	933	1,790	652	1,690	2290
Trojan (Oregon)						
Truck	2,780	1,850	1,190	1,330	302	2630
Rail	2,919	2,210	1,250	1,460	301	2890
MRS facility						
Truck	NA[b]	NA	NA	NA	NA	NA
Rail	520	1,410	1,950	1,470	1,620	NA

[a] These reactors were chosen as representative of regions throughout the country.
[b] NA = not applicable.

Table A-14. Distance per shipment from sources of high-level waste

Source	Distance (miles)				
	Salt			Tuff	Basalt
	Richton	Deaf Smith	Davis Canyon	(Yucca Mt.)	(Hanford)
Hanford					
Truck	2,610	1660	1,010	1,150	NA[a]
Rail	2,670	1,730	1,070	1,288	NA
Idaho National Engineering Laboratory					
Truck	2,160	1,210	604	740	610
Rail	2,110	1,200	555	763	696
Savannah River Plant					
Truck	568	1,420	2,060	2,350	2,740
Rail	644	1,520	2,200	2,750	2,890
West Valley					
Truck	1,160	1,580	2,000	2,750	2,550
Rail	1,450	1,690	2,100	2,860	2,660

[a] NA = not applicable.
[b] Commercial high-level waste.

Table A-15. Total cask-miles for shipments in the authorized and the improved-performance systems (one-way million miles)

Mode and waste type	Repository site				
	Salt			Tuff	Basalt
	Richton	Deaf Smith	Davis Canyon	(Yucca Mt.)	(Hanford)
AUTHORIZED SYSTEM					
100% truck					
Spent fuel	67.4	94.4	115.1	141.8	149.7
Defense high-level waste	28.0	26.0	28.0	33.0	35.0
Commercial high-level waste[a]	1.0	1.0	2.0	2.0	2.0
100% rail					
Spent fuel	11.0	15.4	18.8	23.2	24.6
Defense high-level waste	6.5	6.1	6.5	7.6	8.4
Commercial high-level waste[a]	0.2	0.2	0.2	0.3	0.3
Totals					
Truck from origin	96.4	121.4	145.1	176.8	186.7
Rail from origin	17.7	21.7	25.5	31.1	33.3
IMPROVED-PERFORMANCE SYSTEM					
1. All fuel to MRS facility					
100% truck from origin					
Spent fuel	48.8	48.8	48.8	48.8	48.8
Defense high-level waste	28.0	26.0	28.0	33.0	35.0
Commercial high-level waste[a]	1.0	1.0	2.0	2.0	2.0
100% rail from origin					
Spent fuel	8.0	8.0	8.0	8.0	8.0
Defense high-level waste	6.5	6.1	6.5	7.6	8.4
Commercial high-level waste[a]	0.2	0.2	0.2	0.3	0.3
Rail from MRS facility[b]					
100-ton casks[c]	6.3	15.3	20.6	26.3	25.0
150-ton casks[c]	2.1	5.0	6.7	11.2	8.7
Totals, 100-ton casks					
Truck from origin[d]	84.1	91.1	98.9	110.1	110.8
Rail from origin	21.0	29.6	35.3	42.2	41.7
Totals, 150-ton casks					
Truck from origin[d]	79.9	80.8	85.0	95.0	94.5
Rail from origin	16.8	19.3	21.4	27.1	25.4
2. Western-reactor spent fuel to repository					
Totals, 100-ton casks					
Truck from origin[d]	83.7	85.1	90.4	99.8	101.4
Rail from origin	20.5	27.6	32.5	38.6	38.4
Totals, 150-ton casks					
Truck from origin[d]	80.0	75.8	77.0	86.4	86.8
Rail from origin	16.7	18.3	19.0	25.1	23.8

[a] Waste from West Valley Demonstration Project.
[b] All shipments in dedicated trains.
[c] Includes casks carrying secondary wastes.
[d] Totals for the improved-performance system include both truck shipments from origin to the MRS facility and dedicated-rail shipments from the MRS facility to the repository.

Table A-16. Fraction of travel in population zones from selected reactors and the MRS[a]

Reactor	Salt						Tuff		Basalt		MRS Facility	
	Richton		Deaf Smith		Davis Canyon		(Yucca Mt.)		(Hanford)			
	Truck	Rail	Truck	Rail	Truck	Rail	Truck	Rail	Truck	Rail	Truck	Rail
Maine Yankee (Maine)												
Urban	.01	.02	.01	.03	.01	.01	.01	.01	.01	.02	.01	.03
Suburban	.43	.48	.35	.34	.28	.23	.26	.21	.26	.27	.48	.49
Rural	.57	.50	.64	.63	.71	.76	.74	.78	.73	.71	.51	.48
Crystal River (Florida)												
Urban	0	.01	.01	.02	0	.01	.01	.01	.01	.01	0	.01
Suburban	.19	.18	.23	.24	.22	.17	.17	.16	.19	.18	.32	.26
Rural	.81	.81	.77	.74	.78	.82	.82	.83	.80	.82	.68	.73
Quad-Cities (Illinois)												
Urban	0	.02	0	0	.01	.01	0	.01	0	.01	0	.04
Suburban	.19	.24	.18	.13	.11	.08	.12	.09	.10	.12	.33	.24
Rural	.81	.74	.82	.86	.88	.91	.88	.90	.90	.87	.67	.72
Palo Verde (Arizona)												
Urban	.01	.03	.02	.01	.02	.02	.02	.01	.02	.02	.01	.01
Suburban	.15	.19	.09	.10	.08	.20	.14	.09	.23	.25	.14	.15
Rural	.84	.78	.89	.90	.90	.78	.85	.90	.75	.73	.84	.84
Trojan (Oregon)												
Urban	0	.01	.01	.01	0	.01	0	.02	0	.01	0	.01
Suburban	.16	.11	.13	.09	.19	.14	.18	.10	.35	.17	.17	.11
Rural	.84	.88	.86	.90	.80	.85	.82	.89	.64	.82	.83	.88
MRS facility (Tennessee)												
Urban		.01		.02		.02		.02		.01		
Suburban	NA[b]	.30	NA	.16	NA	.12	NA	.12	NA	.11	NA	NA
Rural		.69		.82		.87		.86		.88		

[a] These reactors were chosen as representative of regions throughout the country.
[b] NA = not applicable.

Table A-17. Fraction of travel in population zones from high-level waste sources

	Salt						Tuff		Basalt	
	Richton		Deaf Smith		Davis Canyon		(Yucca Mt)		(Hanford)	
Waste source	Truck	Rail	Truck	Rail	Truck	Rail	Truck	Rail	Truck	Rail
Hanford										
Urban	.01	0	.01	.01	0	0	0	.01	NA	NA
Suburban	.16	.11	.12	.10	.19	.15	.18	.10	NA	NA
Rural	.84	.89	.87	.89	.81	.84	.82	.89	NA	NA
Idaho National Engr Lab										
Urban	0	.01	.01	.01	.01	.01	.01	.01	0	0
Suburban	.15	.10	.10	.11	.21	.22	.19	.11	.15	.12
Rural	.85	.90	.89	.88	.78	.77	.80	.88	.85	.88
Savannah River Plant										
Urban	.01	.03	.01	.02	0	.02	.01	.02	0	.01
Suburban	.30	.26	.23	.21	.22	.19	.17	.21	.19	.17
Rural	.69	.72	.76	.78	.77	.79	.82	.78	.81	.82
West Valley										
Urban	.01	.03	0	.02	.01	.02	.01	.02	.01	.01
Suburban	.32	.33	.30	.21	.22	.18	.20	.21	.21	.17
Rural	.67	.64	.70	.78	.77	.80	.79	.78	.78	.82

The numbers of shipments from each reactor to the repository and to the MRS facility are given in Tables A-18 and A-19, respectively. The numbers are different because of the difference in the waste-acceptance schedules for the authorized system and the improved-performance system (see Tables A-6 and A-7). Table A-20 provides information on the numbers of shipments to the repository or MRS facility and the numbers of shipments from the MRS facility.

A.8.3.8 Results of population-risk analyses

The risks of radioactive-material transportation must be evaluated for both radiological and nonradiological effects. Since a package does emit small amounts of radiation, a shipment exposes the public during all phases of its journey. People are exposed at stops and along routes even when the package is moving. In addition to the radiological effects, transportation increases the levels of air pollution. Any equivalent-weight shipment of potatoes, bricks, or other nonradioactive materials would have the same effect, but that effect must be evaluated for a complete analysis. In fact, even in most transportation accidents, the traumatic injuries and deaths resulting from an impact or a fire may far outweigh any radiological consequences. Accordingly, in evaluating the potential consequences or risk of any radioactive-material shipment, the injuries and deaths from both radiological and nonradiological causes must be considered.

Tables A-21, A-22, and A-23 summarize the results of the analysis for each of the scenarios evaluated for the authorized system and the improved-performance system. Table A-21, for the authorized system, estimates the total radiological and nonradiological risks for each of the sites and for the cases where all shipments are assumed to be made by truck or by rail. Table A-22 which estimates risks for the improved performance system, shows the results for shipments from the MRS facility in 100-ton casks, which carry disposal containers ready for emplacement in the repository and 150 ton casks which carry thin-wall canisters. Table A-23 is analogous to Table A-22 except that it presents results for the scenarios in which spent fuel from Western reactors is sent directly to the repository, rather than the MRS facility. In all scenarios it was assumed that both defense and commercial high-level waste would be shipped directly to the repository.

Results for two scenarios (the authorized system and one case for the improved-performance system) are presented in more detail in Tables A-24 through A-31. Results are presented by waste type, normal or accident conditions, and population group. Similar details are available in the report by Cashwell et al. (1985) for all scenarios evaluated for this environmental assessment.

Table A-18. Number of shipments to a repository from each reactor site (authorized system)

Reactor name	100% Truck	100% Rail	Reactor name	100% Truck	100% Rail
Farley 1	120	18	Millstone 1	804	111
Farley 2	46	7	Millstone 2	805	106
Palo Verde 1	511	72	Millstone 3	36	6
Palo Verde 2	484	70	Monticello	693	96
Palo Verde 3	448	63	Prairie Island 1	650	92
Arkansas Nuclear One 1	762	108	Prairie Island 2	631	90
Arkansas Nuclear One 2	187	27	Fort Calhoun 1	534	76
Calvert Cliffs 1	893	127	Humboldt Bay	86	12
Calvert Cliffs 2	853	122	Diablo Canyon 2	236	34
Pilgrim 1	761	105	Diablo Canyon 1	279	40
Robinson 2	581	83	Susquehanna 1	652	90
Brunswick 2	799	111	Susquehanna 2	614	85
Brunswick 1	791	109	Peach Bottom 2	1126	156
Perry 1	806	110	Peach Bottom 3	1126	156
Perry 2	747	104	Limerick 1	679	95
Dresden 1	136	18	Limerick 2	421	59
Dresden 2	909	126	Trojan	330	18
Dresden 3	825	114	Fitzpatrick	614	107
Quad Cities 1	862	119	Indian Point 3	714	102
Quad Cities 2	815	113	Seabrook 1	486	69
Zion 1	858	122	Seabrook 2	320	46
Zion 2	824	117	Salem 1	791	113
LaSalle 1	572	79	Salem 2	764	109
LaSalle 2	572	79	Hope Creek 1	509	71
Byron 1	638	88	Ginna	503	71
Byron 2	631	86	Rancho Seco 1	721	103
Braidwood 1	568	83	Summer	12	2
Connecticut Yankee	702	100	San Onofre 1	203	29
Indian Point 1	80	11	San Onofre 2	306	44
Indian Point 2	762	108	San Onofre 3	347	50
Big Rock Point	104	14	South Texas Project 1	594	82
Palisades	796	113	South Texas Project 2	592	82
Midland 2	373	49	Browns Ferry 1	699	135
Midland 1	334	46	Browns Ferry 2	695	140
La Crosse	143	19	Browns Ferry 3	986	137
Fermi 2	609	85	Sequoyah 1	444	46
Oconee 1	759	108	Sequoyah 2	425	42
Oconee 2	612	87	Watts Bar 1	518	74
Oconee 3	779	111	Watts Bar 2	524	74
McGuire 1	115	17	Bellefonte 1	444	64
McGuire 2	73	11	Bellefonte 2	327	47
Beaver Valley 1	735	104	Hartsville A1	463	65
Beaver Valley 2	272	39	Hartsville A2	328	45
Crystal River 3	676	96	Yellow Creek 1	90	13
Turkey Point 3	695	99	Yellow Creek 2	50	8
Turkey Point 4	694	99	Comanche Peak 1	412	58
St. Lucie 1	894	113	Comanche Peak 2	368	53
St. Lucie 2	486	70	Davis-Besse 1	248	31
Hatch 1	312	43	Callaway 1	360	51
Hatch 2	289	40	Vermont Yankee	675	93
Vogtle 1	547	78	Surry 1	748	102
Vogtle 2	416	60	Surry 2	620	77
River Bend 1	465	65	North Anna 1	365	47
Clinton 1	528	74	North Anna 2	295	38
Cook 1	948	135	WNP 2	650	90
Cook 2	933	133	WNP 1	394	56
Duane Arnold	562	79	WNP 3	617	89
Oyster Creek	777	108	Point Beach 1	620	88
Wolf Creek	191	27	Point Beach 2	591	84
Shoreham	270	38	Kewaunee	634	90
Waterford 3	421	61	Yankee	340	48
Maine Yankee	980	140	Brunswick 2	72	10
Three Mile Island 1	723	103	Brunswick 1	80	11
Grand Gulf 1	247	35	Morris BWR pool	150	20
Grand Gulf 2	340	48	Morris PWR pool	175	25
Cooper	771	107	West Valley BWR pool	17	2
Nine Mile Point 1	700	97	West Valley PWR pool	60	8
Nine Mile Point 2	243	33			
				70,553	9,927

Table A-19. Number of shipments to an MRS facility from eastern and western reactors

Reactor name	100% by Truck	100% by Rail	Reactor name	100% by Truck	100% by Rail
arley 1	387	56	Humboldt Bay[a]	86	12
arley 2	513	45	Diablo Canyon 2[a]	209	30
alo Verde 1[a]	366	52	Diablo Canyon 1[a]	252	36
alo Verde 2[a]	339	49	Susquehanna 1	516	71
alo Verde 3[a]	332	47	Susquehanna 2	483	67
Arkansas Nuclear One 1	762	108	Peach Bottom 2	1,126	156
Arkansas Nuclear One 2	495	43	Peach Bottom 3	1,126	156
Calvert Cliffs 1	893	127	Limerick 1	500	70
Calvert Cliffs 2	853	121	Limerick 2	287	40
Pilgrim 1	761	105	Trojan[a]	805	117
Robinson 2	581	83	Fitzpatrick	864	127
Brunswick 2	799	111	Indian Point 3	714	102
Brunswick 1	791	109	Seabrook 1	343	49
Harris 1	160	23	Seabrook 2	177	26
Perry 1	722	100	Salem 1	791	113
Perry 2	579	80	Salem 2	764	109
Dresden 1	136	18	Hope Creek 1	365	51
Dresden 2	909	126	Ginna	503	71
Dresden 3	825	114	Rancho Seco 1[a]	721	103
Quad-Cities 1	862	119	Summer	215	31
Quad-Cities 2	815	113	San Onofre 1[a]	203	29
Zion 1	858	122	San Onofre 2[a]	306	44
Zion 2	824	117	San Onofre 3[a]	348	49
LaSalle 1	669	93	South Texas Project 1	539	77
LaSalle 2	632	87	South Texas Project 2	453	64
Byron 1	593	85	Browns Ferry 1	944	135
Byron 2	552	78	Browns Ferry 2	821	140
Braidwood 1	570	81	Browns Ferry 3	986	137
Braidwood 2	484	69	Sequoyah 1	588	113
Connecticut Yankee	702	100	Sequoyah 2	571	108
Indian Point 1	80	11	Watts Bar 1	465	66
Indian Point 2	762	108	Watts Bar 2	424	61
Big Rock Point	104	14	Bellefonte 1	315	45
Palisades	796	113	Bellefonte 2	199	29
Midland 2	304	43	Hartsville A1	284	40
Midland 1	261	37	Hartsville A2	194	26
La Crosse	143	19	Comanche Peak 1	294	42
Fermi 2	609	85	Comanche Peak 2	257	33
Oconee 1	759	108	Davis Besse 1	321	43
Oconee 2	612	87	Callaway 1	260	38
Oconee 3	779	111	Vermont Yankee	675	93
McGuire 1	334	44	Surry 1	748	106
McGuire 2	268	39	Surry 2	620	88
Catawba 1	241	31	North Anna 1	469	58
Catawba 2	198	25	North Anna 2	420	50
Beaver Valley 1	735	105	WNP 2[a]	605	84
Beaver Valley 2	154	22	WNP 1[a]	251	36
Crystal River 3	676	96	WNP 3[a]	448	63
Turkey Point 3	695	99	Point Beach 1	620	88
Turkey Point 4	694	99	Point Beach 2	591	84
St. Lucie 1	914	130	Kewaunee	634	90
St. Lucie 2	375	54	Yankee	340	48
Hatch 1	512	61	Brunswick 2	72	10
Hatch 2	482	57	Brunswick 1	80	11
Vogtle 1	415	59	Shoreham	201	28
Vogtle 2	290	41	Waterford 3	291	42
River Bend 1	329	45	Maine Yankee	980	140
Clinton 1	407	57	Three Mile Island	723	103
Cook 1	948	135	Grand Gulf 1	318	45
Cook 2	933	133	Grand Gulf 2	210	30
Arnold	572	79	Cooper	771	107
Oyster Creek	777	108	Nine Mile Point 1	700	97
Wood Creek	184	27	Nine Mile Point 2	185	26

Table A-19. Number of shipments to an MRS facility from eastern and western reactors

Reactor name	100% by Truck	100% by Rail	Reactor name	100% by Truck	100% by Rail
Millstone 1	804	111	Fort Calhoun 1	534	76
Millstone 2	949	135	Morris BWR pool	150	20
Millstone 3	227	33	Morris PWR pool	175	25
Monticello	693	96	West Valley BWR pool	17	2
Prairie Island 1	650	92	West Valley PWR pool	60	8
Prairie Island 2	631	90			
			Total	70,568	9,934

[a] Considered a western reactor for this analysis.

Table A-20a. Number of cask shipments: total cask-shipments from reactors

Destination	Mode	Number of cask shipments		
		PWR	BWR	Total
Repository	100 % truck	43,611	26,942	70,553
	100 % rail	6,190	3,737	9,927
MRS facility, all spent fuel	100 % Truck	44,222	26,346	70,568
	100 % Rail	6,267	3,667	9,934
MRS facility, eastern spent fuel only	100 % Truck	40,915	24,382	65,297
	100 % Rail	5,793	3,390	9,183

Table A-20b. Number of cask-shipments: total cask shipments of consolidated spent fuel from MRS facility[a]

Destination (repository site)	Cask size (tons)	All spent fuel	Eastern fuel only
Salt sites[b]	100	8,074	7,500
	150	2,103	1,900
Tuff	100	8,050	7,500
	150	3,186	3,000
Basalt	100	6,610	6,100
	150	1,823	1,700

[a] Estimates of shipment numbers.
[b] Richton, Deaf Smith, or Davis Canyon.

Table A-21. Summary of the risks of transporting spent fuel and high-level wastes for disposal in the authorized system[a]

Mode and risk type	Salt			Tuff	Basalt
	Richton	Deaf Smith	Davis Canyon	(Yucca Mt)	(Hanford)
100% truck					
Radiological	6.3	7.9	9.5	11	12
Nonradiological	19	24	30	36	39
100% rail					
Radiological	0.2	0.2	0.3	0.3	0.3
Nonradiological	1.8	2.1	2.6	3.0	3.2

[a] Risks expressed in numbers of fatalities from radiological and nonradiological causes. The numbers of fatalities from radiological causes include first- and second-generation genetic effects.

Table A-22. Summary of the risks of transportation for the improved-performance system[a,b]

Mode and risk type	Richton	Deaf Smith	Davis Canyon	Yucca Mt.	Hanford
100% Truck, 100-ton cask[c,d]					
Radiological	5.3	5.4	5.4	5.7	5.7
Nonradiological	21	30	35	42	39
100% rail, 100-ton cask[d,e]					
Radiological	0.2	0.3	0.3	0.3	0.3
Nonradiological	6.9	16	22	27	24
100% truck, 150-ton cask[c,f]					
Radiological	5.3	5.3	5.4	5.7	5.7
Nonradiological	17	19	21	27	23
100% rail, 150-ton cask[e,f]					
Radiological	0.2	0.2	0.2	0.3	0.2
Nonradiological	3.0	5.4	6.9	12	7.8

[a] All spent fuel assumed to be sent first to the MRS facility and from there to the repository; all high-level waste assumed to be sent directly to the repository.

[b] Risks expressed in numbers of fatalities from radiological and nonradiological causes. The numbers of radiological fatalities include first- and second-generation genetic effects.

[c] Shipment by truck from reactors and HLW processing plants; shipment in dedicated trains from MRS facility to repository.

[d] Shipment in general-commerce trains from reactors and HLW processing plants; shipment in dedicated trains from MRS facility.

[e] The 100-ton cask carries ready-to-emplace disposal containers.

[f] The 150-ton cask carries thin-walled canisters to be encapsulated in disposal containers at the repository.

Table A-23. Summary of the risks of transporting for disposal in the improved-performance system[a,b]

Mode and risk type	Salt			Tuff	Basalt
	Richton	Deaf Smith	Davis Canyon	(Yucca Mt.)	(Hanford)
100% truck, 100-ton cask[c,d]					
Radiological	5.4	5.0	5.0	5.3	5.3
Nonradiological	20	28	32	39	35
100% rail, 100-ton cask[d,e]					
Radiological	0.2	0.2	0.3	0.3	0.3
Nonradiological	6.5	15	20	25	22
100% truck, 150-ton cask[c,f]					
Radiological	5.3	5.0	5.0	5.2	5.2
Nonradiological	17	18	19	24	21
100% rail, 150-ton cask[d,f]					
Radiological	0.2	0.2	0.2	0.3	0.2
Nonradiological	2.8	5.0	6.4	11	7.3

[a] Spent fuel from eastern reactors assumed to be sent first to the MRS facility and from there to the repository; spent fuel from western reactors assumed to be sent directly to the repository. All high-level waste assumed to be sent directly to the repository.

[b] Risks expressed in numbers of fatalities from radiological and nonradiological causes. The numbers of radiological fatalities include first- and second-generation genetic effects.

[c] Shipment by truck from reactors and HLW processing plants; shipment in dedicated trains from MRS facility to repository.

[d] Shipment in general-commerce trains from reactors and HLW processing plants, shipment in dedicated trains from MRS facility.

[e] The 100-ton cask carries ready-to-emplace disposal containers.

[f] The 150-ton cask carries thin-walled canisters to be encapsulated in disposal containers at the repository.

Table A-24. Transportation risks for authorized system from spent fuel only

Mode and risk type	Salt			Tuff (Yucca Mt.)	Basalt (Hanford)
	Richton	Deaf Smith	Davis Canyon		
RADIOLOGICAL RISK[a]					
Truck transportation					
Normal occupational fatalities	0.7	1.0	1.2	1.4	1.6
Normal nonoccupational fatalities	3.8	5.2	6.5	7.7	8.4
Accident nonoccupational fatalities	0.02	0.03	0.03	0.04	0.04
Total fatalities	4.6	6.2	7.7	9.2	10
Rail transportation					
Normal occupational fatalities	0.06	0.07	0.09	0.1	0.1
Normal nonoccupational fatalities	0.08	0.08	0.1	0.1	0.1
Accident nonoccupational fatalities	0.02	0.02	0.02	0.02	0.02
Total fatalities	0.2	0.2	0.2	0.2	0.2
NONRADIOLOGICAL RISK					
Truck transportation					
Normal nonoccupational fatalities	0.2	0.2	0.4	0.4	0.4
Accident occupational fatalities	2.7	3.9	5.2	6.4	6.8
Accident nonoccupational fatalities	9.6	14	18	23	24
Accident occupational injuries	5.5	7.7	10	12	13
Accident nonoccupational injuries	160	220	290	370	380
Total fatalities	13	18	24	29	31
Rail transportation					
Normal nonoccupational fatalities	0.1	0.1	0.1	0.2	0.2
Accident occupational fatalities	0.07	0.09	0.1	0.1	0.1
Accident nonoccupational fatalities	1	1.3	1.7	2.1	2.1
Accident occupational injuries	9.2	12	15	19	19
Accident nonoccupational injuries	1.9	2.4	3.2	4.0	4.0
Total fatalities	1.2	1.5	1.9	2.4	2.4

[a] Radiological fatalities include first- and second-generation genetic effects.

Table A-25. Transportation risks for the authorized system from high-level waste only

Mode and risk type	Salt			Tuff	Basalt
	Richton	Deaf Smith	Davis Canyon	(Yucca Mt.)	(Hanford)
RADIOLOGICAL RISK[a]					
Truck transportation					
Normal occupational fatalities	0.3	0.3	0.3	0.3	0.3
Normal nonoccupational fatalities	1.5	1.5	1.5	1.8	1.8
Accident nonoccupational fatalities	0.001	0.001	0.001	0.001	0.001
Total fatalities	1.8	1.8	1.8	2.1	2.1
Rail transportation					
Normal occupational fatalities	0.03	0.03	0.03	0.04	0.04
Normal nonoccupational fatalities	0.03	0.03	0.03	0.04	0.04
Accident nonoccupational fatalities	0.0011	0.001	0.001	0.002	0.001
Total fatalities	0.6	0.06	0.07	0.08	0.08
NONRADIOLOGICAL RISK					
Truck transportation					
Normal occupational fatalities	0.02	0.1	0.05	0.1	0.02
Accident occupational fatalities	1.4	1.3	1.3	1.6	1.6
Accident nonoccupational fatalities	4.8	4.7	4.7	5.7	5.8
Accident occupational injuries	2.7	2.6	2.6	3.1	3.2
Accident nonoccupational injuries	76	75	75	90	91
Total fatalities	6.2	6.2	6.1	7.4	7.4
Rail transportation					
Normal occupational fatalities	0.03	0.04	0.04	0.04	0.04
Accident occupational fatalities	0.04	0.04	0.04	0.04	0.05
Accident nonoccupational fatalities	0.6	0.6	0.6	0.6	0.7
Accident occupational injuries	5.3	5.3	5.4	5.3	6.6
Accident nonoccupational injuries	1.1	1.1	1.1	1.1	1.4
Total fatalities	0.6	0.6	0.7	0.6	0.8

[a] Radiological fatalities include first- and second-generation genetic effects.

Table A-26. Total transportation risks for the authorized system

Mode and risk type	Salt			Tuff (Yucca Mt.)	Basalt (Hanford)
	Richton	Deaf Smith	Davis Canyon		
RADIOLOGICAL RISK[a]					
[redacted]ck transportation					
Normal occupational fatalities	1	1.3	1.5	1.7	1.9
Normal nonoccupational fatalities	5.3	6.6	8.0	9.5	10
Accident nonoccupational fatalities	0.03	0.03	0.03	0.04	0.04
Total fatalities	6.3	7.9	9.5	11	12
[redacted]l transportation					
Normal occupational fatalities	0.1	0.1	0.1	0.1	0.1
Normal nonoccupational fatalities	0.1	0.1	0.1	0.1	0.2
Accident nonoccupational fatalities	0.02	0.02	0.02	0.02	0.02
Total fatalities	0.2	0.2	0.3	0.3	0.3
NONRADIOLOGICAL RISK					
[redacted]ck transportation					
Normal nonoccupational fatalities	0.2	0.3	0.4	0.6	0.4
Accident occupational fatalities	4.1	5.2	6.5	8	8.4
Accident nonoccupational fatalities	14	18	23	28	30
Accident occupational injuries	8.1	10	13	16	17
Accident nonoccupational injuries	230	300	370	450	470
Total fatalities	19	24	30	37	39
[redacted]l transportation					
Normal nonoccupational fatalities	0.2	0.2	0.2	0.2	0.2
Accident occupational fatalities	0.1	0.1	0.2	0.2	0.2
Accident nonoccupational fatalities	1.5	1.8	2.2	2.6	2.8
Accident occupational injuries	14	17	21	25	26
Accident nonoccupational injuries	3	3.5	4.3	5.1	5.4
Total fatalities	1.8	2.1	2.6	3.0	3.2

[a] Radiological fatalities include first- and second-generation genetic effects.

Table A-29. Transportation risks for the improved-performance s
secondary waste from the MRS facility to the repos

Type of risk	Salt		
	Richton	Deaf Smith	Davis Canyon
	RADIOLOGICAL RISK[b]		
Normal occupational fatalities	0.0008	0.001	0.002
Normal nonoccupational fatalities	0.005	0.008	0.009
Accident nonoccupational fatalities	0.006	0.01	0.01
Total fatalities	0.008	0.02	0.02
	NONRADIOLOGICAL RISK		
Normal nonoccupational fatalities	0.008	0.02	0.03
Accident occupational fatalities			
Accident nonoccupational fatalities			
Accident occupational injuries			
Accident nonoccupational injuries			
Total fatalities	0.008	0.02	0.03

[a] Estimated risks of shipping secondary waste (spent-fuel-assembly
high-activity low-level waste, and contact-handled transuranic w
facility to the repository. All secondary-waste shipments assum
train in 100-ton casks.

[b] Radiological fatalities include first- and second-generation gen

Table A-26. Total transportation risks for the authorized system

Mode and risk type	Salt			Tuff (Yucca Mt.)	Basalt (Hanford)
	Richton	Deaf Smith	Davis Canyon		
RADIOLOGICAL RISK[a]					
Truck transportation					
Normal occupational fatalities	1	1.3	1.5	1.7	1.9
Normal nonoccupational fatalities	5.3	6.6	8.0	9.5	10
Accident nonoccupational fatalities	0.03	0.03	0.03	0.04	0.04
Total fatalities	6.3	7.9	9.5	11	12
Rail transportation					
Normal occupational fatalities	0.1	0.1	0.1	0.1	0.1
Normal nonoccupational fatalities	0.1	0.1	0.1	0.1	0.2
Accident nonoccupational fatalities	0.02	0.02	0.02	0.02	0.02
Total fatalities	0.2	0.2	0.3	0.3	0.3
NONRADIOLOGICAL RISK					
Truck transportation					
Normal nonoccupational fatalities	0.2	0.3	0.4	0.6	0.4
Accident occupational fatalities	4.1	5.2	6.5	8	8.4
Accident nonoccupational fatalities	14	18	23	28	30
Accident occupational injuries	8.1	10	13	16	17
Accident nonoccupational injuries	230	300	370	450	470
Total fatalities	19	24	30	37	39
Rail transportation					
Normal nonoccupational fatalities	0.2	0.2	0.2	0.2	0.2
Accident occupational fatalities	0.1	0.1	0.2	0.2	0.2
Accident nonoccupational fatalities	1.5	1.8	2.2	2.6	2.8
Accident occupational injuries	14	17	21	25	26
Accident nonoccupational injuries	3	3.5	4.3	5.1	5.4
Total fatalities	1.8	2.1	2.6	3.0	3.2

[a] Radiological fatalities include first- and second-generation genetic effects.

Table A-27. Transportation risks for the improved-performance system from shipping spent fuel from reactors to the MRS facility[a]

Mode and risk type	Salt			Tuff (Yucca Mt.)	Basalt (Hanford)
	Richton	Deaf Smith	Davis Canyon		
RADIOLOGICAL RISK[b]					
Truck transportation					
Normal occupational fatalities	0.6	0.6	0.6	0.6	0.6
Normal nonoccupational fatalities	3	3	3	3	3
Accident nonoccupational fatalities	0.02	0.02	0.02	0.02	0.02
Total fatalities	3.6	3.6	3.6	3.6	3.6
Rail transportation					
Normal occupational fatalities	0.05	0.05	0.05	0.05	0.05
Normal nonoccupational fatalities	0.07	0.07	0.07	0.07	0.07
Accident nonoccupational fatalities	0.02	0.02	0.02	0.02	0.02
Total fatalities	0.1	0.1	0.1	0.1	0.1
NONRADIOLOGICAL RISK					
Truck transportation					
Normal nonoccupational fatalities	0.2	0.2	0.2	0.2	0.2
Accident occupational fatalities	2	2	2	2	2
Accident nonoccupational fatalities	7	7	7	7	7
Accident occupational injuries	4.1	4.1	4.1	4.1	4.1
Accident nonoccupational injuries	120	120	120	120	120
Total fatalities	9.1	9.1	9.1	9.1	9.1
Rail transportation					
Normal nonoccupational fatalities	0.1	0.1	0.1	0.1	0.1
Accident occupational fatalities	0.05	0.05	0.05	0.05	0.05
Accident nonoccupational fatalities	0.8	0.8	0.8	0.8	0.8
Accident occupational injuries	7	7	7	7	7
Accident nonoccupational injuries	1.4	1.4	1.4	1.4	1.4
Total fatalities	0.9	0.9	0.9	0.9	0.9

[a] Estimated risks of shipping all spent fuel from reactors to the MRS facility. The risks are the same for all four of the scenarios discussed in the text.

[b] Radiological fatalities include first- and second-generation genetic effects.

Table A-28. Transportation risks for the improved-performance system from shipping consolidated spent fuel from the MRS facility to the repository[a]

Risk type	Salt			Tuff	Basalt
	Richton	Deaf Smith	Davis Canyon	(Yucca Mt.)	(Hanford)
		RADIOLOGICAL RISK[b]			
Normal occupational fatalities	0.002	0.004	0.005	0.006	0.005
Normal nonoccupational fatalities	0.02	0.02	0.02	0.03	0.03
Accident nonoccupational fatalities	0.006	0.01	0.01	0.01	0.01
Total fatalities	0.02	0.04	0.04	0.05	0.04
		NONRADIOLOGICAL RISK			
Normal nonoccupational fatalities	0.01	0.09	0.1	0.1	0.07
Accident occupational fatalities	0.3	0.9	1.3	1.6	1.4
Accident nonoccupational fatalities	5	14	19	24	21
Accident occupational injuries	47	130	180	220	190
Accident nonoccupational injuries	9.7	26	36	46	40
Total fatalities	5.4	15	20	25	22

[a] Estimated risks from shipping consolidated spent fuel from the MRS facility to the repository. All shipments assumed to be by dedicated train in 100-ton casks carrying ready-to-emplace disposal containers.

[b] Radiological fatalities include first- and second-generation genetic effects.

Table A-29. Transportation risks for the improved-performance system from shipping secondary waste from the MRS facility to the repository[a]

Type of risk	Salt			Tuff	Basalt
	Richton	Deaf Smith	Davis Canyon	(Yucca Mt.)	(Hanford)
	RADIOLOGICAL RISK[b]				
Normal occupational fatalities	0.0008	0.001	0.002	0.002	0.002
Normal nonoccupational fatalities	0.005	0.008	0.009	0.01	0.014
Accident nonoccupational fatalities	0.006	0.01	0.01	0.02	0.02
Total fatalities	0.008	0.02	0.02	0.03	0.02
	NONRADIOLOGICAL RISK				
Normal nonoccupational fatalities	0.008	0.02	0.03	0.04	0.03
Accident occupational fatalities					
Accident nonoccupational fatalities					
Accident occupational injuries					
Accident nonoccupational injuries	———	———	———	———	———
Total fatalities	0.008	0.02	0.03	0.04	0.03

[a] Estimated risks of shipping secondary waste (spent-fuel-assembly hardware, high-activity low-level waste, and contact-handled transuranic waste) from the MRS facility to the repository. All secondary-waste shipments assumed to be by dedicated train in 100-ton casks.

[b] Radiological fatalities include first- and second-generation genetic effects.

Table A-30. Transportation risks for the improved-performance system from shipping high-level waste to the repository[a]

Mode and risk type	Salt			Tuff	Basalt
	Richton	Deaf Smith	Davis Canyon	(Yucca Mt.)	(Hanford)
RADIOLOGICAL RISK[b]					
Truck transportation					
Normal occupational fatalities	0.3	0.3	0.3	0.3	0.3
Normal nonoccupational fatalities	1.5	1.5	1.5	1.8	1.8
Accident nonoccupational fatalities	0.001	0.001	0.001	0.001	0.001
Total fatalities	1.8	1.8	1.8	2.1	2.1
Rail transportation					
Normal occupational fatalities	0.03	0.03	0.03	0.04	0.04
Normal nonoccupational fatalities	0.03	0.03	0.03	0.04	0.04
Accident nonoccupational fatalities	0.001	0.001	0.001	0.002	0.001
Total fatalities	0.06	0.06	0.07	0.08	0.07
NONRADIOLOGICAL RISK					
Truck transportation					
Normal nonoccupational fatalities	0.02	0.1	0.05	0.1	0.02
Accident occupational fatalities	1.4	1.3	1.3	1.6	1.6
Accident nonoccupational fatalities	4.8	4.7	4.7	5.7	5.8
Accident occupational injuries	2.7	2.6	2.6	3.1	3.2
Accident nonoccupational injuries	76	75	75	90	91
Total fatalities	6.2	6.2	6.2	7.4	7.4
Rail transportation					
Normal nonoccupational fatalities	0.03	0.04	0.04	0.06	0.04
Accident occupational fatalities	0.04	0.04	0.04	0.05	0.05
Accident nonoccupational fatalities	0.6	0.6	0.6	0.7	0.7
Accident occupational injuries	5.3	5.3	5.4	6.9	6.6
Accident nonoccupational injuries	1.4	1.1	1.1	1.4	1.4
Total fatalities	0.63	0.64	0.66	0.84	0.79

[a] Estimated risk of shipping high-level waste directly to the repository. All shipments assumed to be in 100-ton casks.

[b] Radiological fatalities include first- and second-generation genetic effects.

Table A-31. Total transportation risks for the improved-performance system[a]

Mode and risk type	Salt			Tuff	Basalt
	Richton	Deaf Smith	Davis Canyon	(Yucca Mt.)	(Hanford)
RADIOLOGICAL RISK[b]					
Truck transportation[c]					
Normal occupational fatalities	0.9	0.8	0.9	0.9	0.9
Normal nonoccupational fatalities	4.5	4.4	4.5	4.7	4.8
Accident nonoccupational fatalities	0.03	0.05	0.05	0.06	0.05
Total fatalities	5.3	5.4	5.4	5.7	5.7
Rail transportation[d]					
Normal occupational fatalities	0.09	0.09	0.09	0.1	0.1
Normal nonoccupational fatalities	0.1	0.1	0.1	0.1	0.1
Accident nonoccupational fatalities	0.03	0.04	0.04	0.05	0.04
Total fatalities	0.2	0.3	0.3	0.3	0.3
NONRADIOLOGICAL RISK					
Truck transportation[c]					
Normal nonoccupational fatalities	0.2	0.4	0.4	0.5	0.3
Accident occupational fatalities	3.7	4.3	4.6	5.2	5.0
Accident nonoccupational fatalities	17	25	30	36	33
Accident occupational injuries	54	130	180	230	200
Accident nonoccupational injuries	200	220	230	250	250
Total fatalities	21	30	35	42	39
Rail transportation[d]					
Normal nonoccupational fatalities	0.2	0.3	0.3	0.4	0.3
Accident occupational fatalities	0.4	1.0	1.4	1.7	1.5
Accident nonoccupational fatalities	6.3	15	20	25	22
Accident occupational injuries	59	140	190	240	210
Accident nonoccupational injuries	12	25	39	49	43
Total fatalities	6.9	16	22	27	24

[a] Estimated risks of shipping (1) all spent fuel from reactors to the MRS facility, (2) consolidated spent fuel from the MRS facility to the repository, (3) secondary waste from the MRS facility to the repository, and (4) high-level waste directly to the repository. All shipments from the MRS facility assumed to be in 100-ton casks.

[b] Radiological fatalities include first- and second-generation genetic effects.

[c] Shipment by truck from reactors and HLW processing plants; shipment in dedicated trains from MRS facility to repository.

[d] The 100-ton cask carries ready-to-emplace disposal containers.

A.8.3.9 Uncertainties

The results presented here are to be used only in comparing potential repository sites, because their absolute values, though considered to be representative, have acknowledged uncertainties associated with them. Important ones include the following:

1. The risk analysis (Section A.8.2.8) was performed on a national scale, using aggregate input from large regions. As a result, these inputs are averaged and may not accurately reflect information for a specific route.

2. The packaging capacities are not known at this time nor are actual exposure rates for new casks.

3. Some inputs will be refined during the studies conducted concurrently with site characterization and during the preparation of the environmental impact statement.

A.9 COST ANALYSIS

Early efforts at defining the transportation-system equipment and operating requirements for the repository were initiated in the late 1970s, when it was recognized that transportation is an important factor in repository siting. This section summarizes the method, assumptions, and models used in analyzing the costs of waste transportation.

A.9.1 OUTLINE OF METHOD

The analysis in this environmental assessment makes use of the models developed to evaluate the costs of transporting waste to a repository. The analysis is dependent on a logistics code, WASTES, which analyzes the cost of transport and hardware requirements (Shay et al., 1985). The hardware costs, both maintenance and capital, are evaluated by using the output from WASTES. The total costs can therefore be thought of as the composite value of shipping costs, hardware capital expenditures, and maintenance allowances. All three factors are highly dependent on the assumptions underlying the analysis.

A.9.2 ASSUMPTIONS

In calculating costs, the spent-fuel discharge data published in a recent DOE report (Heeb et al., 1985) were used. In all scenarios a total of 62,000 MTU of spent fuel is shipped from individual reactor sites. The specific amounts of spent fuel to be shipped from each reactor site were selected on a yearly basis by applying the following criteria:

1. Reactors experiencing a loss of full-core-reserve (FCR) capacity within a given year were given the highest priority.

2. Reactors undergoing decommissioning were given the next highest priority 2 years after their last year of operation.

3. The oldest fuel remaining at reactors was given final priority.

The other major assumptions used in this analysis are described below (see Cashwell et al., 1985, for details).

A.9.3 MODELS

The WASTES model was used to calculate shipping costs and the size of the cask fleet. This model has been benchmarked against past analyses. A good discussion of the capabilities of WASTES is presented by Shay et al. (1985).

A.9.4 COST ESTIMATES

The costs of transporting waste in the various scenarios are shown in Table A-32. Estimates for the authorized system and two scenarios for the improved-performance system are presented in sufficient detail to show the costs of shipping the various types of waste. Only summary results are presented for the other scenarios, but details are available in the report by Cashwell et al. (1985). The results for the same two scenarios are provided in Tables A-33 and A-34 except that different detail is highlighted. In these tables, the three major cost components are shown for spent-fuel shipments only. The basis for the capital and maintenance costs is given in Tables A-35 and A-36. It should be noted in Table A-35 that the cask-maintenance costs are for 15 years--the assumed life of a cask. Table A-36 estimates the numbers of casks needed over the lifetime of the repository for each of the various scenarios.

The costs of transporting high-level waste are given in Tables A-37 and A-38 for each of the repository sites and for each mode considered.

A.9.5 LIMITATIONS OF RESULTS

The results presented should be used only to compare the potentially acceptable sites. As absolute values, they are limited for several reasons:

1. No attempt was made to escalate costs for inflation. All costs are in constant 1985 dollars.

2. The transportation-distance estimates will be affected by the selected routes.

Table A-32. Total transportation cost
(millions of dollars)

Mode and waste type	Repository Site				
	Richton	Deaf Smith	Davis Canyon	Yucca Mt.	Hanford
AUTHORIZED SYSTEM					
100% Truck					
Spent fuel	722	922	1,080	1,286	1,345
Defense high-level waste	207	195	214	237	254
Commercial high-level waste[a]	7	8	10	15	15
100% Rail					
Spent fuel	699	832	917	1,024	1,055
Defense high-level waste	272	279	278	308	308
Commercial high-level waste[a]	10	10	11	12	12
Totals					
Truck from origin	936	1,127	1,305	1,538	1,615
Rail from origin	982	1,122	1,207	1,345	1,376
IMPROVED-PERFORMANCE SYSTEM					
1. All fuel to the MRS facility					
100% truck from origin					
Spent fuel	600	600	600	600	600
Defense high-level waste	207	195	214	237	254
Commercial high-level waste[a]	7	8	10	15	15
100% rail from origin					
Spent fuel	594	593	593	593	593
Defense high-level waste	272	279	278	308	308
Commercial high-level waste[a]	10	10	11	12	12
Rail from MRS, 100-ton casks					
Spent fuel in disposal containers	421	638	728	800	693
Assembly hardware and high-activity waste	80	124	144	164	173
Contact-handled transuranic waste	8	9	9	10	10
Rail from MRS, 150-ton casks					
Spent fuel in disposal containers	157	212	236	412	248
Assembly hardware and high-activity waste	87	123	140	147	172
Contact-handled transuranic waste	8	9	10	10	11

Table A-32. Total transportation cost (Continued)
(millions of dollars)

Mode and waste type	Repository Location				
	Richton	Deaf Smith	Davis Canyon	Yucca Mt.	Hanford
IMPROVED-PERFORMANCE SYSTEM (Continued)					
1. All fuel to the MRS facility (Continued)					
Total cost, 100-ton casks					
Truck from origin	1,323	1,576	1,709	1,828	1,748
Rail from origin	1,384	1,654	1,767	1,889	1,792
Total cost, 150-ton casks					
Truck from origin	1,065	1,149	1,210	1,422	1,301
Rail from origin	1,127	1,227	1,268	1,483	1,345
2. Western-reactor spent fuel directly to the repository					
Total cost, 100-ton casks					
Truck from origin	1,265	1,439	1,560	1,674	1,562
Rail from origin	1,328	1,537	1,640	1,760	1,628
Total cost, 150-ton casks					
Truck from origin	1,046	1,084	1,126	1,308	1,205
Rail from origin	1,109	1,182	1,206	1,394	1,271

[a] High-level waste from the West Valley Demonstration Project.

Table A-33. Costs of transportation from reactors to repository in the authorized system[a,b] (millions of dollars)

Repository site	Shipping	Capital	Maintenance	Total
		ALL SHIPMENTS BY RAIL		
Richton	390	202	108	699
Deaf Smith	477	232	123	832
Davis Canyon	534	250	134	917
Yucca Mountain	604	275	146	1,024
Hanford	626	280	150	1,055
		ALL SHIPMENTS BY TRUCK		
Richton	442	181	99	722
Deaf Smith	595	212	116	922
Davis Canyon	717	235	128	1,080
Yucca Mountain	876	266	145	1,286
Hanford	922	274	149	1,345

[a] Spent fuel only.
[b] Values have been rounded.

Table A-34. Costs of transportation in the improved-performance system[a,b] (millions of dollars)

Repository site	Shipping	Capital	Maintenance	Total
RAIL SHIPMENTS TO AND FROM THE MRS FACILITY				
Richton	598	248	256	1,102
Deaf Smith	799	354	212	1,365
Davis Canyon	895	277	306	1,477
Yucca Mountain	963	379	227	1,569
Hanford	906	354	211	1,471
TRUCK SHIPMENTS TO, AND RAIL SHIPMENTS FROM, THE MRS FACILITY				
Richton	623	236	250	1,108
Deaf Smith	824	342	207	1,372
Davis Canyon	919	265	300	1,485
Yucca Mountain	988	367	222	1,576
Hanford	931	342	206	1,479

[a] All spent fuel sent first to the MRS facility and from there to the repository, after consolidation. All shipments in 100-ton casks.

[b] Cost estimates do not include high-level waste, and values have been rounded.

Table A-35. Capital and maintenance costs
(millions of 1985 dollars)

Transportation mode	Capital[a]	Maintenance[b]
Reactor to MRS facility		
Truck cask	1.5	0.075
Rail cask	2.5	0.125
MRS facility to repository		
100-ton rail cask	2.5	0.125
150-ton rail cask	2.75	0.125
Rail package for transuranic waste[c]	1.6	0.075
Defense high-level waste[d]		
Truck cask	1.1	0.06
Rail cask	1.8	0.09

[a] Capital costs are for each cask and include the cost of trailer or railcar.

[b] Maintenance costs are per package-year for the assumed 15-year cask life.

[c] Based on two packages per railcar.

[d] Includes commercial high-level waste from the West Valley Demonstration Project.

Table A-36. Total requirements for transportation packaging
(Number of casks)

Mode and waste type	Repository site: Richton	Deaf Smith	Davis Canyon	Yucca Mt.	Hanford
AUTHORIZED SYSTEM					
100% truck					
Spent fuel	124	145	161	182	188
Defense high-level waste	40	43	48	50	53
Commercial high-level waste	2	2	2	4	4
100% rail					
Spent fuel	81	93	100	110	112
Defense high-level waste	34	36	38	42	44
Commercial high-level waste	2	2	2	2	2
IMPROVED-PERFORMANCE SYSTEM					
1. All spent fuel to the MRS facility					
100% truck from origin					
Spent fuel	106	106	106	106	106
Defense high-level waste	40	44	48	51	56
Commercial high-level waste	2	2	2	4	4
100% rail from origin					
Spent fuel	67	67	67	67	67
Defense high-level waste	34	37	38	42	47
Commercial high-level waste	2	2	2	2	2
Rail from MRS, 100-ton casks					
Spent fuel in disposal containers	55	70	75	80	70
High-activity waste	4	4	4	4	4
Contact-handled TRU waste	2	2	2	2	2
Rail from MRS, 150-ton casks					
Spent fuel in canisters	20	20	20	30	20
High-activity waste	8	8	8	6	10
Contact-handled TRU waste	2	2	2	2	2
2. Western-reactor spent fuel to the repository					
100% Truck from origin					
Spent fuel	111	108	106	105	106
Defense high-level waste	40	44	48	51	56
Commercial high-level waste	2	2	2	4	4
100% rail from origin					
Spent fuel	70	69	67	67	67
Defense high-level waste	34	37	38	42	47
Commercial high-level waste	2	2	2	2	2
Rail from MRS, 100-ton casks					
Spent fuel in disposal canisters	50	60	70	70	60
High-activity waste	4	4	4	4	4
Contact-handled TRU work	2	2	2	2	2
Rail from MRS, 150-ton casks					
Spent fuel in canisters	20	20	20	30	20
High-activity waste	8	8	8	6	8
Contact-handled TRU waste	2	2	2	2	2

Table A-37. Costs of transporting high-level waste by truck[a] (millions of 1985 dollars)

Source and destination	Shipping	Capital	Maintenance	Total
Savannah River Plant				
Hanford	135	48	26	210
Yucca Mountain	110	42	23	175
Deaf Smith	63	31	17	111
Richton	34	22	12	68
Davis Canyon	97	40	22	158
Hanford				
Hanford	NA	NA	NA	NA
Yucca Mountain	10	3	3	16
Deaf Smith	15	4	4	23
Richton	24	6	4	34
Davis Canyon	9	3	3	15
Idaho National Engineering Laboratory				
Hanford	26	10	8	44
Yucca Mountain	29	10	8	47
Deaf Smith	40	12	10	62
Richton	74	16	14	105
Davis Canyon	23	10	8	41
West Valley Demonstration Plant[b]				
Hanford	9	4	2	15
Yucca Mountain	8	4	2	15
Deaf Smith	5	2	1	9
Richton	4	2	1	7
Davis Canyon	7	2	1	10

[a] Values have been rounded.

[b] Commercial high-level waste.

Table A-38. Costs of transporting high-level waste by rail[a]
(Millions of 1985 dollars)

Source and destination	Shipping	Capital	Maintenance	Total
SRP to				
Hanford	142	65	32	240
Yucca Mountain	126	54	27	208
Deaf Smith	92	43	22	157
Richton	56	32	16	105
Davis	118	50	25	193
Hanford to				
Hanford	NA	NA	NA	NA
Yucca Mountain	15	5	4	25
Deaf Smith	20	5	4	30
Richton	26	7	5	39
Davis	14	5	4	24
INEL to				
Hanford	44	14	11	69
Yucca Mountain	48	16	12	77
Deaf Smith	64	16	12	92
Richton	91	22	16	129
Davis	39	13	10	61
West Valley to				
Hanford	7	4	2	12
Yucca Mountain	7	4	2	12
Deaf Smith	5	3.6	2	10
Richton	4	4	2	10
Davis	6	4	2	11

[a] Values have been rounded.

3. Published tariffs were used in this analysis where available; however, under the deregulation that has recently occurred, the DOE will be able to negotiate with carriers for rates and services, and shipping costs may change.

A.10 BARGE TRANSPORTATION TO REPOSITORIES

The most likely way in which barge transportation would be used to make shipments to a repository would be to complete a partial leg of the journey. In all cases, barges cannot be loaded directly from the reactor-pool loading area without the use of heavy-haul truck equipment or a railcar. In the barge scenario for eastern reactors evaluated by Tobin and Meshkov (1985), it was considered likely that a reactor within 483 kilometers (300 miles) of a large port capable of handling large railcasks and served by a railroad would ship by rail and then use a barge through an intermodal transfer. The eastern reactors for which barge transport was considered to be a feasible option are listed in Table A-39. The shipment from the reactor would then proceed as far as possible by barge, and then another intermodal transfer would occur back to a railroad. This transfer point was assumed to be either in the Gulf of Mexico or on the Mississippi River. Therefore, the shipment would arrive at the repository by railcar. The possible exception where barge loadings and unloadings could be made directly would be a specially designed cask-handling facility at the MRS facility. Because a barge has tremendous capacity (equivalent to at least four rail casks), it is highly inefficient to use small truck casks.

The results given in Table A-40 for the risk from barge transportation generally show that barge transportation increases occupational exposure for normal operations during the shipment of spent fuel. Because barge shipments require intermodal transfer at both ends of the journey, the workers involved in this activity receive relatively high radiation doses and account for the large increase in occupational exposure over the rail mode. The exposure of the public is also increased by the intermodal transfers.

The results presented in Table A-40 are a first attempt at characterizing barge transportation. The numbers are expected to be refined as further studies are conducted to provide models of similar detail as those available for the truck and rail modes. As in previous studies for truck and rail modes, when data are not well characterized, assumptions are made that tend to overpredict the actual values. However, reactor-specific results presented by Tobin and Meshkov (1985) suggest that under several circumstances the barge mode may reduce risk.

Tobin and Meshkov did not investigate the consequences of barge accidents because a previous study (Unione et al., 1978) was found to contain analyses for barge accidents that were similar to those used by Sandquist et al. (1985) for truck and rail accidents. The results of that study are shown in Tables A-41 and A-42. These results can be compared with the equivalent categories in Table A-5. Table A-42 is comparable to results for water release. The results show accidents from barges to be of the same order as for other modes.

Table A-39. Reactor sites included in barge study

Direct to water[a]				Rail to water[b]	
Transfer at Houston[c]		Transfer at Memphis[d]		Transfer at Houston	
Plant	State	Plant	State	Plant	State
Brunswick	North Carolina	Big Rock Point	Michigan	Hatch	Georgia
Calvert Cliffs	Maryland	Browns Ferry	Alabama	McGuire	North Carolina
Crystal River	Florida	Cook	Michigan	North Anna	Virginia
Farley	Alabama	Davis-Besse	Ohio	Peach Bottom	Pennsylvania
Indian Point	New York	Dresden	Illinois	Robinson	South Carolina
Maine Yankee	Maine	Fitzpatrick	New York	Summer	South Carolina
Millstone	Connecticut	Ginna	New York	Susquehanna	Pennsylvania
Oyster Creek	New Jersey	Kewaunee	Wisconsin	Three Mile Island	Pennsylvania
Pilgrim	Massachusetts	Nine Mile Point	New York	Vermont Yankee	Vermont
Salem	New Jersey	Palisades	Michigan		
St. Lucie	Florida	Point Beach	Wisconsin		
Surry	Virginia	Sequoyah	Tennessee		
Turkey Point	Florida	Zion	Illinois		

[a] Plants located on a waterway.
[b] Plants located within 300 miles of port.
[c] Shipments to Houston are by ocean.
[d] Shipments to Memphis are by inland waterway.

Table A-40. Projected latent cancers for shipments to repositories from reactors with barge access[a,b]

Type of transfer	Deaf Smith		Yucca Mountain		Hanford	
	Barge/rail	All rail	Barge/rail	All rail	Barge/rail	All rail
Offshore to Gulf of Mexico						
Nonoccupational	0.03	0.02	0.04	0.03	0.05	0.03
Occupational	0.09	0.014	0.1	0.02	0.1	0.02
Inland waterways to Mississippi River						
Nonoccupational	0.02	0.01	0.03	0.02	0.03	0.015
Occupational	0.08	0.01	0.08	0.015	0.08	0.015
Rail to water and Gulf of Mexico						
Nonoccupational	0.05	0.01	0.06	0.01	0.06	0.01
Occupational	0.05	0.007	0.06	0.01	0.06	0.01
Total, 35 reactor sites						
Nonoccupational	0.10	0.04	0.13	0.05	0.14	0.06
Occupational	0.22	0.03	0.24	0.05	0.24	0.05
Total	0.32	0.07	0.37	0.10	0.38	0.10

[a] Considers shipments from reactors listed in Table A-39 according to schedule given by Tobin and Meshkov (1985).
[b] Analysis was made only for three potential repository sites.

Table A-41. Summary of the radiological air-release consequences of airborne releases from barge accidents[a]

Accident class[c]	Latent-cancer fatalities[b] Average	Maximum
4	5×10^{-11}	2×10^{-9}
5	6×10^{-6}	2×10^{-4}
6	0.01	0.2

[a] Estimates based on data presented by Unione et al. (1978, Table 6.4).
[b] Based on the assumption that a population dose of 1 man-rem induces 0.0002 latent-cancer fatality plus first- and second-generation genetic effects.
[c] Accident classes from Wilmot et al. (1983).

Table A-42. Summary of the radiological consequences of waterborne releases from barge accidents[a]

Specific dose pathway	Latent-cancer fatalities[b]
Drinking water	1.0
Fresh-water fish	4
Shoreline deposits	0.02
Irrigated crops	0.1
Total of all pathways	5

[a] Estimates based on data presented by Unione et al. (1978, Table 6.16).
[b] Based on the assumption that a population dose of 1 man-rem induces 0.0002 latent-cancer fatality plus first-and second generation genetic effects.

Shipping by barge may be more expensive than the rail mode. Tobin and Meshkov suggest that shipping spent fuel by barge and rail to a repository could cost from $38 to $47 per kilogram of uranium, but these numbers are high because new cost estimates for casks are lower than those used in their study. If values from Table A-35 are substituted, the adjusted cost for barge transportation becomes $27 to $34 per kilogram of uranium. This compares with a range for rail of $13 to $17 per kilogram of uranium, or approximately half the barge and rail cost. The barge-and-rail cost can be reduced by adding more casks to each barge; Tobin and Meshkov assume four railcasks on a barge. It is feasible to ship at least six casks on a barge.

A primary objective of the Tobin and Meshkov study was to determine whether barge transportation is a discriminating factor in site selection. It can be inferred, however, from Table A-40 and from the preliminary estimates of cost per kilogram of uranium shipped that barge transportation will augment the other modes and will be used in special circumstances where the other modes are not available. Since all shipments in the region of the repository site will be completed by rail or truck even if barges are used, no site has a significant advantage because of its proximity to a nearby port. For example, the Richton site may appear to be better than Yucca Mountain because of its proximity to the Gulf of Mexico, but there is no advantage because a shipment to either site must be completed by rail. Similarly, barges on the Columbia River could arrive within about 16 miles of the Hanford site, but this option does not appear reasonable or probable for eastern reactors because of the additional crew exposure, cost, and time required to complete a shipment via the Panama Canal. Administrative concerns, including safeguarding and travel through foreign countries, add to the unlikeliness of this option. As can be seen in Figure A-4, some reactors west of the longitude 100°W could ship to the Hanford site using intermodal transfers. The Trojan plant in Oregon as well as the Humboldt Bay and Diablo Canyon plants in California could possibly ship directly if the proper dock facilities were available. It is not likely that a barge can land at San Onofre in California. Power plants in Arizona and the Rancho Seco plant in California are also not likely to ship by barge because rail shipments would have to be made to a suitable port. In each case, this port is likely to be densely populated, and therefore there is little incentive to use barges.

No additional insight for ranking sites is gained from Table A-40. At this preliminary stage in the evaluation of the barge mode for its feasibility and safety, it is concluded that the barge option is not a discriminating element in comparing sites.

A.11 EFFECT OF THE SECOND REPOSITORY ON TRANSPORTATION ESTIMATES

The analyses that have been discussed to this point (see Section A.8.3) do not explicitly consider the effect of the second repository; however, the siting guideline on transportation requires the second repository to be considered in the cost and risk analyses. A supplementary analysis was performed to predict the expected uncertainty in the results for a single repository when a second repository is added to the waste-management system.

Figure A-4. Reactors west of 100° W longitude.

A.11.1 SINGLE-REPOSITORY ANALYSES

The impacts resulting from shipments from reactors to the repository have been evaluated for both the authorized system and the improved-performance system.

In the authorized system, spent fuel and high-level waste are shipped directly to the repository. The spent fuel that was assumed to be shipped is generally the oldest fuel, except when a reactor that is running out of storage capacity is given preference. The geographic location of the fuel is not considered.

In the scenarios analyzed for the improved-performance system, similar assumptions were made about the fuel that is shipped, but the fuel is sent first to the MRS facility and then to the repository. Four variations of the improved-performance system were considered. The first two assumed that all of the spent fuel that is received by the repository is routed through the MRS facility. These two variations differ only in the size of the cask assumed to be used for shipments from the MRS facility to the repository (100 and 150 tons). Defense high-level waste is sent directly to the repository; it does not pass through the MRS facility.

Two other variations were generated by taking into account the geographic distribution of some of the fuel. In these variations, about 4,500 MTU of spent fuel from the reactors west of the Rockies is sent to the first repository without passing through the MRS facility. The remaining fuel is preferentially selected by age except for cases where reactors have no storage capacity. These two variations are also distinguishable because two different cask sizes were assumed for each.

None of the variations of the improved-performance system or the authorized system fully consider the geographic distribution of fuel; some do not consider it at all.

A.11.2 LOGIC SUPPORTING THE SUPPLEMENTARY ANALYSIS

If a second repository is introduced into the waste-management system, the spent fuel that will be sent to the first repository can be chosen not only for the age of the fuel but also for the proximity of the fuel to the repository. Logic and the mandate of the Act appear to dictate that fuel closest to the first repository should be shipped to it, with the remainder being shipped to the second repository. When an MRS facility is added to the waste-management system, the ideal fuel selection for the first repository would be the fuel farthest from the second repository (approximately nearest the first repository).

The second repository will enter the system several years after the first. Consequently, its effect on the population of reactors shipping to the first repository will be somewhat reduced because the reactors with storage problems would likely not be restricted from shipment to a more distant first repository as long as their storage problems remained. The supplementary analysis more closely represents a system that simultaneously has two

repositories in operation and therefore will manifest the greatest effect of regionality on the transportation impacts.

A.11.3 DESCRIPTION OF SUPPLEMENTARY ANALYSES

Two separate analyses were performed: one that considered the MRS facility and another that did not. For each analysis, two cases were considered: (1) the first repository receives spent fuel from reactors closest to it and (2) the first repository receives spent fuel from reactors farthest from it (Figure A-5). Only Yucca Mountain is shown in Figure A-5; however, similar figures were generated for analyses for each of the five sites nominated as suitable for characterization.

The major assumptions are as follows:

- The cumulative spent-fuel quantities were assumed to be those of the "midcase" projection by the DOE's Energy Information Administration (EIA).
- Estimates based on adjusted "great circle" distances.
- Use of 150-ton casks for shipments from the MRS facility.
- All spent fuel routed through the MRS facility.
- Only spent fuel was assumed to be shipped.

The results are presented in Table A-43. Only cask-miles were calculated because cask-miles are a good surrogate measure of transportation costs and risks. Table A-44 contains the percentage variation from the single-repository values. It can be seen that the introduction of a second repository can produce a significant effect on the results for a single-repository analysis.

A.12 CRITERIA FOR APPLYING THE TRANSPORTATION GUIDELINE

The siting guideline on transportation (10 CFR 960.5-2-7) contains a number of terms that are subject to interpretation. These terms are underlined in Table A-45, which is a complete listing of both the favorable and the potentially adverse conditions of the guideline. Terms like "short," "economical," "cuts," and "fills" are clearly open to interpretation. These common terms generally defy the application of accepted objective definitions.

Early in the process of implementing the guideline, it was recognized that a consistent set of criteria was needed to apply the transportation guideline. In September 1984, an ad hoc transportation group was established to deal with transportation issues in the environmental assessments (EAs). The group included a member from the DOE Project Offices representing the three host rocks considered for the first repository and representing substantial expertise in the transportation of radioactive waste. One member had been instrumental in drafting the guideline itself. Before the issuance of the draft EAs, this group developed criteria for applying favorable conditions 1, 2, and 3 and potentially adverse conditions 1 and 3. These

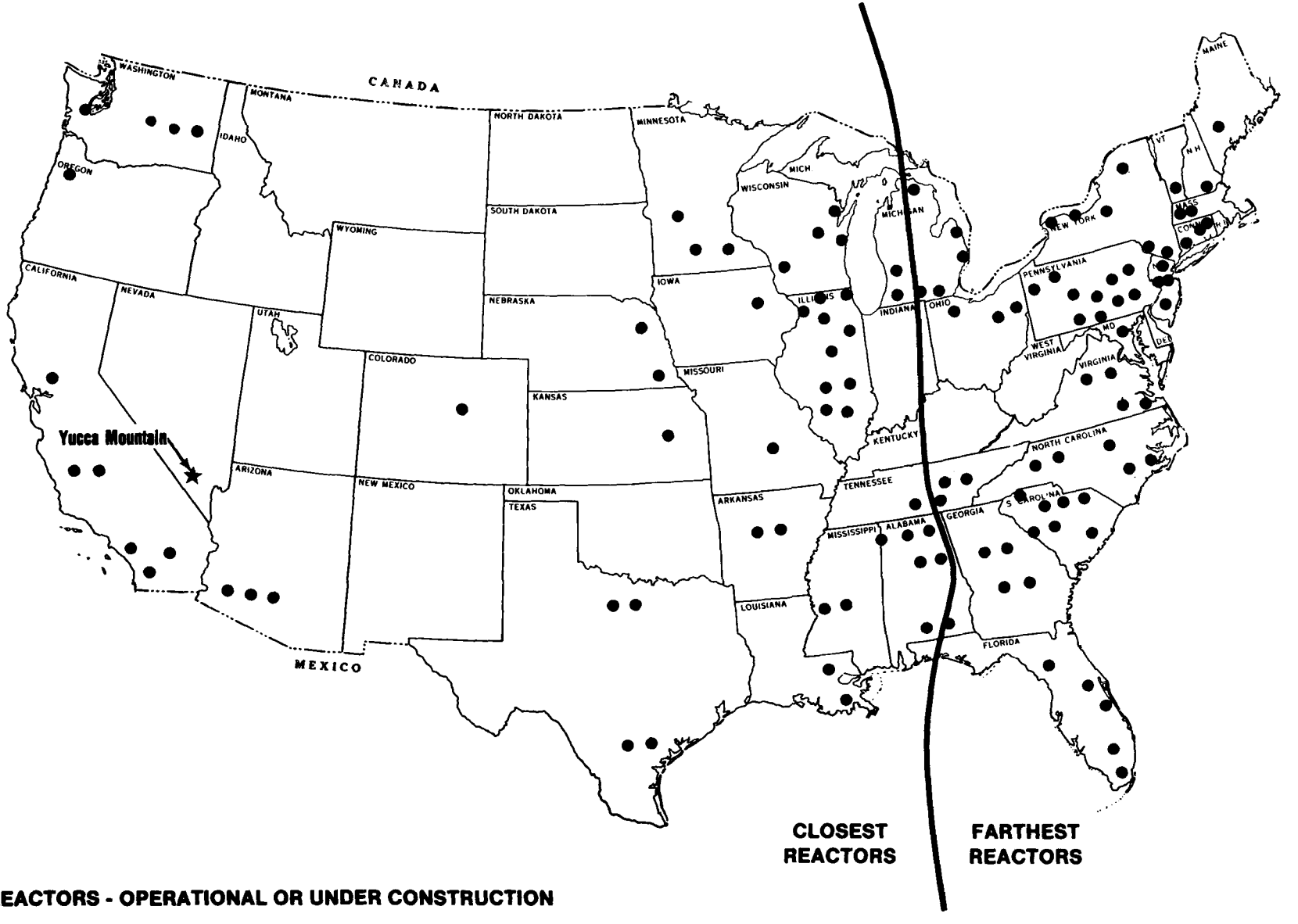

Figure A-5. Analysis of shipping from farthest and closest reactors to Yucca Mountain.

Table A-43. Cask-miles from reactors to potential repository locations with and without an MRS facility[a] (Millions of cask-miles)

Repository site	Without MRS facility			With MRS facility		
	Closest	EA Analysis	Farthest	Closest	EA Analysis	Farthest
Richton	6.5	11.0	15.3	5.1	9.2	14.0
Deaf Smith	11.6	15.4	18.7	6.8	10.9	15.7
Davis Canyon	14.1	18.8	22.7	7.8	11.9	16.7
Yucca Mountain	17.4	23.2	27.6	11.4	15.6	20.3
Hanford	19.2	24.6	28.9	8.6	12.8	17.5

[a] Estimates based on the shipment of 62,000 MTU of spent fuel.

Table A-44. Percent variation in cask-miles resulting from the introduction of second repository

Repository site	Without MRS facility		With MRS facility	
	Closest	Farthest	Closest	Farthest
Richton	-46	+40	-44	+52
Deaf Smith	-30	+23	-38	+44
Davis Canyon	-29	+22	-34	+40
Yucca Mountain	-29	+21	-27	+30
Hanford	-25	+19	-33	+37

Table A-45. Criteria for applying the transportation guideline

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FAVORABLE CONDITIONS

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

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

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

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

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

(v) Such routes bypass local cities and towns.

Criterion

All parts of this favorable condition pertain to the access route to the repository. The access route is the road or railspur that must be constructed to connect existing roads or track with the site. Only one part need be present.

(i) The favorable condition is present if the access route is less than 10 miles long and costs less than $10 million. These criteria are applied to truck and rail routes separately.

(ii) If any part of the access route must be constructed over private land, it is assumed that Federal condemnation will be required, and the favorable condition is not present

(iii) All road or track construction requires cuts and fills. Cuts and fills for generally flat terrain are considered acceptable. The favorable condition is not present if bridges or tunnels are required.

(iv) The favorable condition is present if the access road is constructed over generally flat terrain.

(v) The favorable condition is not present if the access route passes through a highly populated area, as defined in 10 CFR Part 960, Subpart A, or 960.5-2-1(c)(2) (Federal Register, Vol. 49, pp. 47754 and 47763, respectively).

Table A-45. Criteria for applying the transportation guideline (Continued)

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

Criterion

This favorable condition pertains to that segment of existing track between the outer end of the access route and the nearest State, Federal, or interstate highway and the nearest mainline railroad that does not require upgrading or repair. This segment of road or track should be no longer than 10 miles and cost no more than $10 million.

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

Criterion

This distance refers to the length of the road or track between the outer end of the access route and the nearest State, Federal, or interstate highway or the nearest mainline railroad. This distance should be no more than 30 miles. Distance to a waterway is not considered because a barge shipment would have to offload onto a railroad.

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

Criterion

All sites have at least one railroad interchange point at the point where the site spur joins the mainline. All other interchanges within 125 miles of the site will be counted. The site with the fewest interchanges will be considered to have the favorable condition present.

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

Criterion

All sites will be compared; only one site will have the favorable condition present.

Table A-45. Criteria for applying the transportation guideline (Continued)

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

Criterion

This favorable condition is present if any carrier--truck, rail, or water--is available within the minimum transportation study area.

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

Criterion

This favorable condition will be addressed as explained in Appendix C.

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

Criterion

Any evidence that emergency-response plans, procedures, and capabilities exist will be favorable. Evidence for all of these is required for a finding that the favorable condition is present.

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

Criterion

The repository activity is significantly disrupted if it is not able to meet its annual acceptance rate.

Table A-45. Criteria for applying the transportation guideline (Continued)

POTENTIALLY ADVERSE CONDITIONS

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

Criterion

An expensive access route is considered to be one that costs more than $10 million.

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

Criterion

This potentially adverse condition is present if the terrain over which the access route must pass is not generally flat and if the access route must cross a river or lake.

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

Criterion

This potentially adverse condition is present if a significant reconstruction or upgrading of a truck or rail route costs more than $10 million. This criterion is applied separately to truck and rail routes.

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

Criterion

Examples of local conditions that are potentially adverse are proximity to a bombing range, extreme costs, and despoiling of the environmental and aesthetic qualities of pristine land.

criteria were applied during the ranking process documented in Chapter 7 of the draft EAs.

The process by which the criteria were developed relied heavily on the collective transportation expertise of the ad hoc group. Rules-of-thumb were often used to make estimates in the context of indefinite terms. For example, the cost of a mile of new highway or railroad track is often assumed to be $1 million when the route traverses flat terrain. Such an estimate might be used when much additional information is not available. The application of such rules, experience, and informed judgment allowed more-definitive criteria to be developed while considering the requirement to judge transportation conditions in the context of "comparable siting options." In other words, the criteria values were developed by fully considering the range and distribution of values for all of the five sites nominated as suitable for characterization.

The comments on the draft EAs noted other inconsistencies in the findings reported for the transportation guideline, particularly for the conditions that contain the term "regional". The DOE then decided to develop criteria for all of the conditions in the transportation guideline. Through repeated discussions with the ad hoc committee members, the final criteria presented in Table A-45 were promulgated in August 1985. Again, the process of criteria development relied on the judgment of the transportation ad hoc group.

A.13 COMMON QUESTIONS REGARDING TRANSPORTATION

A.13.1 PRENOTIFICATION

Many States wish to be notified in advance of certain radioactive-waste shipments.

Whether prenotification results in an increase in safety is the subject of considerable discussion among Federal regulatory agencies and State and local governments. Currently, the NRC, under Congressional mandate, requires NRC licensees to notify States in advance of spent-fuel and certain radioactive-waste shipments (10 CFR 71.97 and 73.37(f)). The DOT requires postnotification of shipments (49 CFR 173.22(d)). In an effort to understand the issue and to gauge the efficacy of the NRC regulation, the DOE sponsored a study (Pellettieri and Welles, 1985). Currently, the DOE and the DOT have completed a joint study that surveyed the State, local, and facility notification requirements for hazardous materials (Dively et al., 1985).

The DOE currently provides State officials with generic notification of its shipments of radioactive material. This notification reviews the type and quantity of shipments but does not designate the time and the date of shipment. For current shipments in support of the OCRWM research and development program, the DOE is supplementing this generic notification with courtesy communications to an appropriate officer of each State through which the shipment will pass. In light of the number of spent-fuel shipments to repositories, the DOE will evaluate its current procedures for tracking radioactive-waste shipments and consider a number of additional options. For

example, an effective real-time shipment-tracking system may be a preferable alternative to prenotification. Decisions will be based on the best technology available and applicable laws and regulations in use at the time of shipment to a waste-management facility.

A.13.2 EMERGENCY RESPONSE

Emergency response to a transportation accident involving radioactive material is another concern of State and local officials.

State and local jurisdictions have the primary responsibility for emergency response to incidents occurring in connection with all hazardous materials, including spent-fuel shipments. Federal assistance can be provided in many ways, however. For example, the DOE will make available from its resources such radiological advice and assistance as is requested and appropriate to protect public health and safety and to cope with radiological hazards. DOE personnel will respond to requests from NRC licensees; Federal, State, and local authorities; and private persons or companies, including carriers. Assistance can be obtained from any one of eight DOE regional centers, which are capable of responding to radiological incidents on a 24-hour basis. Requests for aid are handled directly through the DOE regional centers or through an emergency clearing house called CHEMTREC (Chemical Transportation Emergency Center) that is sponsored and funded by the chemical industry. The DOE offices, when requested, will provide radiation assistance teams.

For States hosting facilities developed under the Act, the DOE will seek to negotiate written agreements that can address assistance and funding for emergency-response preparations. In other States, funding or assistance in lieu of funding (e.g., training courses, equipment, etc.) will continue to be available through the Federal Emergency Management Agency (FEMA) or other Federal agencies. Examples of the type of assistance already provided by the Federal Government are the emergency-response workshops for first responders sponsored by the DOE at various locations in the country each year as part of its compliance training program.

The FEMA has coordinated the development of the interim Federal Radiological Emergency Response Plan (Federal Register, Vol. 49, p. 35896). The interim plan outlines procedures to be taken in the event of nuclear accidents, including those involving the transportation of radioactive waste, and is designed to provide coordinated Federal response in support of State and local governments. Under the plan, State and local governments have the primary responsibility for responding to emergencies; Federal technical assistance is provided on request. In addition, the FEMA has published interim Guidance for Developing State and Local Radiological Emergency Response Plans and Preparedness for Transportation Accidents (FEMA, 1983). This guidance, which is currently being revised, provides a basis for State and local governments to develop emergency plans and improve emergency preparedness for transportation accidents involving radioactive materials.

A.13.3 HIGHWAY ROUTING

A.13.3.1 Highway routing regulations

The routing of radioactive-waste shipments is a primary concern of State, local, and tribal officials. On January 19, 1981, the DOT by its authority under the Hazardous Materials Transportation Act, published a final rule governing the highway routing of radioactive materials. Designated HM-164, this rule has been codified as 49 CFR Parts 171, 172, 173, and 177. The DOE will, of course, comply with all DOT regulations.

According to HM-164, highway carriers of "highway route controlled quantity radioactive materials" (e.g., spent nuclear fuel) are required to use "preferred routes." A preferred route consists of an interstate highway, including the use of interstate beltways or bypasses when available to avoid city centers, or alternative routes that are designated by a State routing agency (which includes the appropriate authorities of Indian Tribes). State-designated alternative routes must be selected in accordance with DOT guidelines for selecting preferred highway routes (DOT, 1984) or an equivalent routing analysis that adequately considers the overall risk to the public.

The DOT stated that it followed three basic concepts in devising a highway-routing framework for radioactive materials:

1. Route selection should be based on some valid measure of reduced risk to the public.

2. Uniform and consistent rules for route selection are needed from both a practical and a safety standpoint.

3. Local views should be carefully considered in routing decisions because routing is a site-specific activity unlike other transportation controls, such as marking and packing (Federal Register, Vol. 46, p. 5299).

The DOT's approach to routing acknowledges that public policy for the routing of radioactive materials should be based on a consideration of the overall risk involved in transporting such materials. The risk depends on such factors as accident rates, total travel time, traffic patterns, population density, road conditions, time of travel, and driver training. Further, the DOT recognized the need to balance local and national interests in routing decisions while providing for uniformity and consistency of transportation regulations. With regard to the acknowledged need to provide for local input in routing decisions, the DOT provided for the designation of alternative routes to interstate highways by State routing agencies in consultation with affected localities, neighboring States, and Indian Tribes and in accordance with DOT guidelines, to ensure the consideration of all impacts and continuity of designated routes.

Carriers of spent fuel may deviate from a preferred route under the following three circumstances:

1. Emergency conditions that would make continued use of the preferred route unsafe.

2. To make necessary rest, fuel, and vehicle-repair stops.

3. To the extent necessary to pick up, deliver, or transfer a large-quantity package of radioactive materials (49 CFR 177.825(b)(2)).

HM-164 has numerous other provisions designed to ensure the safe highway shipment of radioactive materials. These include the requirement for the provision of written route plans to the shipper and specific driver-training requirements, which include knowledge of procedures to be followed in an accident or other emergency.

There are several methods by which the DOE can support the highway-routing efforts of the States and the DOT. On request, the DOE will assist the States as practicable in the evaluation and determination of State-designated alternative routes. The DOE, as the shipper of record, will continue to notify its carriers of the State-designated alternative routes and will instruct that these routes be used during all shipments. Moreover, the carrier will be instructed that all safety and routing requirements must be met and that lack of compliance will result in appropriate sanctions, including the potential suspension of carriers (41 CFR 109-40.103-1). Federal and State reports of carrier performance, postnotification of routes, and DOE tracking of actual shipments will provide mechanisms by which operations can be monitored. In addition to diligent and consistent observance of these currently available procedures, the DOE will continue to coordinate with the States concerning the routing of any highway route controlled quantities (49 CFR 173.403) of radioactive materials shipped by the DOE.

A.13.3.2 State and local ordinances

As discussed in the preceding section, the DOT derives its authority to regulate hazardous-materials transportation principally from the Hazardous Materials Transportation Act (HMTA). The HMTA (Section 112(a)) preempts "...any requirement of a state or political subdivision thereof, which is inconsistent with any requirement set forth in [the HMTA] or regulations issued under [the HMTA]." Thus, State or local actions are not necessarily precluded; only those that are "inconsistent" are preempted. The DOT can, however, grant an exemption from this blanket preemption provision to allow an inconsistent State or local requirement to remain in effect. Such an exemption can be granted if, mainly because of local considerations, the requirement (1) affords an equal or greater level of protection to the public than is afforded by the requirements of the HMTA or of regulations issued under the HMTA and (2) does not unreasonably burden commerce.

In its general discussion of the highway-routing rule, the DOT notes its conclusion that "the public risks in transporting [radioactive] materials by highway are too low to justify the unilateral imposition by local governments of bans and other severe restrictions on the highway mode of transportation" (Federal Register, Vol. 46, p. 5299).

Appendix A to 49 CFR Part 177 delineates DOT policy regarding the consistency of State and local rules with DOT highway-routing requirements for the purpose of advising State or local governments how they can exercise their responsibilities with respect to the regulation of motor carriers. The DOT generally regards State and local requirements to be inconsistent if they--

- Prohibit the transportation of large-quantity radioactive materials by highway between any two points without providing an alternative route for the duration of the prohibition.
- Conflict with NRC or DOT physical-security requirements.
- Require additional or special personnel, equipment, or escort.
- Require additional or different shipping paper entries, placards, or other hazard-warning devices.
- Require filing route plans or other documents containing information that is specific to individual shipments.
- Require prenotification.
- Require accident or incident reporting other than as immediately necessary for emergency assistance.
- Unnecessarily delay transportation.

A.13.4 RAILROADS

A.13.4.1 Railroad routing

There are no regulatory requirements for the routing of rail shipments. Rail-shipment routes depend largely on the railroad to which the shipment is originally consigned and how that (and each successive) railroad handles interconnections with other railroads.

A.13.4.2 Rail regulations

Several government agencies perform inspection-and-enforcement activities to promote the safe transportation of radioactive materials on the nation's railroads. Since rail is a predominantly interstate mode of transportation, the Federal Government has long been considered the entity best equipped to develop, promulgate, and enforce a uniform set of safety regulations for the transportation of hazardous materials by rail.

The safety and safeguards regulations for shipments of radioactive material by rail, in many cases, are the same as those for highway shipments. The NRC has issued general routing guidelines for rail shipments of spent

fuel, which are included in its physical-protection requirements that were promulgated to guard against acts of sabotage for both rail and truck spent-fuel shipments. The DOT has issued specific rules limiting both the number and the duration of rail stops and designating the placement of cars carrying spent fuel in the makeup of the train. In addition, there are standards for track quality and other operating features of importance to safety of rail transport.

Shippers who prepare material for rail transportation are required to comply with DOT regulations found in 49 CFR Part 173 before offering any hazardous material shipment to a carrier. The responsibilities of rail carriers of radioactive waste are outlined in DOT regulations 49 CFR Part 174. In accepting a shipment, the carrier inspects it visually to ascertain that the hazardous material is not leaking, that specific rail equipment (air and handbreaks, journal boxes, and trucks) is working properly, and that appropriate placards are provided. The carrier cannot accept packages that are leaking or damaged. In addition to the DOT requirements, rail companies inspect railcars periodically to ensure that they are mechanically safe for operation. In particular, certain equipment is routinely inspected at interchange points by the carrier.

Carrier operations are also subject to DOT regulations covering safety enforcement procedures, track safety standards, and accident-reporting procedures. Under the conditions of 49 CFR 171.15 and 171.16, the carrier must notify the DOT immediately of any unintentional release of a hazardous material during the course of transportation and must submit a written hazardous materials incident report to DOT within 15 days of such an event.

Although jurisdiction over the transport of radioactive waste by rail is vested primarily in the Federal Government, States and local governments that wish to assume specific responsibilities in this area also have a role. The Federal Rail Safety Act (45 U.S.C. 434) directs that a State may enforce its own railroad safety regulation provided that the State regulation is (1) consistent with Federal regulations, (2) necessary to eliminate or reduce an essentially local safety hazard, and (3) not a burden on the free flow of interstate commerce.

The DOE's Office of Civilian Radioactive Waste Management (OCRWM) is investigating means for facilitating a cooperative effort among affected Federal and State agencies and the railroad industry in forging shipping arrangements that are safe, efficient, and equitable. There appears to be a strong willingness by all affected parties to work toward this goal.

The DOE will reinforce the DOT's and the NRC's inspection-and-enforcement activities through the establishment of a comprehensive quality-assurance and quality-control program to address each aspect of the transportation process, including the integrity of the shipping casks and the procedures for handling the casks. The quality-assurance program will implement systematic procedures designed to ensure and provide demonstrable evidence that program goals, such as safety, reliability, and maintainability, are achieved in a cost-effective manner.

A.13.4.3 Dedicated trains

The use of "dedicated trains" involves the designation of specific equipment (locomotives, cask cars, buffer cars, and cabooses) for the use of a particular commodity between fixed origin and destination points. In many respects, it is similar to the "sole-use" vehicle that is commonly employed by motor carriers for specific commodities (one example is the transportation of bulk, low-specific-activity radioactive material).

Special arrangements to expedite the movement of dedicated trains can be made among railroads. For example, the equipment "dedicated" for sole use may be owned by the originating carrier. This equipment could be used for the full length of the move. There may be no switching or interchange with other carriers at terminals along the route. After delivery, the empty cars are returned to the origin for the next movement, possibly under the same expedited process as the loaded train. The originating carrier and the carriers that own and operate the rail lines to be used by the dedicated train would agree on the apportionment of revenues among themselves for the entire move.

A.13.5 INSURANCE COVERAGE FOR TRANSPORTATION ACCIDENTS

The Price-Anderson Act of 1957 (42 U.S.C. Sections 2014 and 2210, as amended) provides extensive liability coverage for damages suffered by the public in the event of nuclear accidents at certain facilities (which include commercial nuclear power reactors and DOE contractor-operated facilities) or accidents that occur in the course of transportation to or from such facilities. Liability coverage extends to all potentially responsible parties (except, in some instances, the Federal Government, whose liability would be covered under the Federal Tort Claims Act) and is not limited to parties who actually purchase insurance or enter into indemnity agreements with the Federal Government.

State law is generally used to determine liability and the extent of damages in the event of a nuclear incident; the Price-Anderson Act in turn establishes a system for paying for those damages. The Act places restrictions on the use of State law in the event of an "extraordinary nuclear occurrence" (ENO) at certain facilities--an occurrence that involves substantial offsite releases of radiation and is likely to result in substantial offsite damages to persons or property. When the Federal Government determines that an extraordinary nuclear occurrence has occurred, certain defenses available under State law must be waived. One waiver requires the imposition of strict liability, without proof of negligence on the part of any responsible party. Defenses related to governmental immunity are also waived. The Price-Anderson Act further declares that in the event of an extraordinary nuclear occurrence, defenses based on statutes of limitations will be waived if a suit is brought within "three years from the date that the claimant first knew, or reasonably could have known, of his injury or damage and the cause thereof, but in no event more than twenty years after the date of a nuclear incident." A State statute of limitations that allows a greater period of time for filing suit would remain in effect.

Another important feature of the Price-Anderson Act is the monetary limitation on liability. To the extent that damages exceed the amount of coverage required by the Act, all responsible parties are relieved of further liability; Congress is then required to investigate the incident and take appropriate action.

The Price-Anderson Act provides for liability coverage through a system of private insurance and government indemnity. Under the Act's private insurance system, utility owners of large NRC-licensed commercial nuclear power reactors are required to maintain the maximum amount of insurance available from private sources (currently, $160 million). Should claims arising from a nuclear incident (related to the activities of such NRC licensees) exceed the amount of primary insurance, all licensees of large nuclear power reactors would be assessed up to $5 million per reactor. With 98 large reactors now licensed to operate (as of January 1986), a second layer of coverage is provided in the amount of $490 million. Both forms of coverage provide a total of $640 million in the event of a serious nuclear incident at a nuclear power plant or an incident occurring in the course of transportation to or from such a facility.

The Price-Anderson Act also authorizes the DOE to enter into indemnity agreements with its contractors for activities, under contract and conducted for the benefit of the United States, that involve "the risk of public liability for a substantial nuclear incident." The indemnity coverage under such contracts provides that, in the event of a nuclear incident arising out of, or in connection with, a contractual activity, the contractor and any other person who may be liable would be indemnified by the DOE, up to the statutory limit of $500 million. Indemnity coverage under DOE agreements further extends to nuclear incidents arising in the course of transportation to or from contractor locations. The DOE does not require contractors to carry additional liability insurance because the cost of any such insurance would be passed on to the DOE. Since the enactment of the Nuclear Waste Policy Act, the DOE has indicated that indemnity agreements based on the Price-Anderson Act will be included in its contracts for the operation of any DOE facility associated with the waste-management program (e.g., a geologic repository and MRS facility, if approved by Congress). Under the indemnity agreement, the DOE is to indemnify the facilities' operating contractor and any other person who may be liable for a nuclear incident arising out of, or in connection with, radioactive waste management. Coverage for waste-management activities would extend to transportation to or from a waste-management facility.

Congressional review of the Price-Anderson Act is now under way and is expected to be completed by 1987, when the Act will expire unless reauthorized. The DOE has offered recommendations to Congress pertaining to the Act's contractor indemnity system and the application of that system to activities conducted under the Nuclear Waste Policy Act. Such recommendations include the following:

- Extended liability coverage. While a limitation on liability is supported, the DOE has recommended that the extent of coverage under DOE indemnity agreements be comparable to that afforded by large commercial utilities.

- Explicit coverage of activities conducted under the Nuclear Waste Policy Act. While the DOE believes that the present language of the Price-Anderson Act is sufficient to permit indemnification coverage for nuclear waste operations, explicit coverage under the Act is supported.

- Application of ENO provisions to waste-management activities. The DOE supports the extension of the Act's ENO provisions, with the related waiver of defenses, to incidents connected with the transportation, storage, and disposal of civilian and defense high-level waste.

- Source of funding. The DOE supports the provision of liability coverage for waste-management activities conducted under the Nuclear Waste Policy Act through expenditures of the Nuclear Waste Fund (which in turn is financed through fees paid by the generators and owners of radioactive waste).

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Appendix B

AVAILABILITY OF REFERENCES

Appendix B

AVAILABILITY OF REFERENCES

B.1 REFERENCES CITED IN ALL EAs

The references cited in all of the draft and the final environmental assessments (EAs) are available for public review in DOE reading rooms at the following locations.

U.S. Department of Energy
Public Reading Room
FOI, Room 1E-190
1000 Independence Avenue, S.W.
Washington, DC 20585

Albuquerque Operations Office
National Atomic Museum
Kirkland Air Force Base East
Albuquerque, NM 87116

Chicago Operations Office
9800 South Cass Avenue
Argonne, IL 60439

Idaho Operations Office
550 Second Street
Idaho Falls, ID 83401

Nevada Operations Office
2753 South Highland Drive
Las Vegas, NV 89109

Oak Ridge Operations Office
Federal Building
Oak Ridge, TN 37830

Richland Operations Office
Federal Building
Richland, WA 99352

San Francisco Operations Office
Wells Fargo Building
1333 Broadway
Oakland, CA 95612

Savannah River Operations Office
Savannah River Plant
Aiken, SC 29801

B.2 REFERENCES CITED IN THE EA FOR THE BASALT (HANFORD) SITE

The references cited in the EA for the Hanford site are available for public review at the following locations:

Idaho

Boise Public Library and
Information Center
715 Capitol Boulevard
Boise, ID 83702

Lewiston City Library
428 Thain Road
Lewiston, ID 83501

Coeur D'Alene Public Library
703 Lakeside Avenue
Coeur D'Alene, ID 83814

University of Idaho Library
(Federal Depository)
Moscow, ID 83843

Oregon

Portland State University
(Federal Depository)
Bradford Price Millar Library
934 Southwest Harrison
Portland, OR 97207

Umatilla County Library
214 North Main Street
Pendleton, OR 97801

Washington

University of Washington Libraries
M-171 Library, FM-25
Seattle, WA 98195

Central Washington University
D and 11 Street
Ellensburg, WA 98926

Washington State Library
(Federal Depository)
Temple of Justice
Olympia, WA 98504

Pasco Public Library
1320 West Hopkins
Pasco, WA 99301

Seattle Public Library
1000 Fourth Avenue
Seattle, WA 98104

Fort Vancouver Regional Library
1007 East Mill Plain Boulevard
Vancouver, WA 90663

Prosser Public Library
902 Seventh Street
Prosser, WA 99350

State of Washington Dept. of Ecology
Office of High-Level Nuclear Waste
Management
Reference Center
5826 Pacific Avenue
Lacey, WA 98504

Eastern Washington University
John F. Kennedy Memorial
Cheney, WA 99004

Washington State University Library
Holland Library, Room 221
Library Road
Pullman, WA 99164-5610

Mid-Columbia Library
405 South Dayton
Kennewick, WA 99336

Richland Public Library
Swift and Northgate
Richland, WA 99352

Spokane Public Library
Comstock Building Library
West 906 Main Avenue
Spokane, WA 99201

Walla Walla Public Library
238 East Adler
Walla Walla, WA 99362

U.S. Department of Energy
Reading Room, Hanford Science
Center
825 Jadwin Avenue
Richland, WA 99352

Yakima Valley Regional Library
102 North Third Street
Yakima, WA 98901

B.3 REFERENCES CITED IN THE EA FOR THE SALT SITES

The references cited in the EAs for the Davis Canyon, Utah, Deaf Smith, Texas, and Richton, Mississippi, are available for public review at the following locations:

Louisiana

Minden Nuclear Waste Information Office
221 Main Street
Minden, LA 71005

Bienville Parish Library
604 South Maple
Arcadia, LA 71001

Webster Parish Library
521 East and West Streets
Minden, LA 71005

Mississippi

Richton Nuclear Waste Information Office
103 Dogwood
Richton, MS 39476

Harrison County Library
14th Street and 21st Avenue
Gulfport, MS 39510

Pine Forest Regional Library
Main Street
Richton, MS 39476

Jackson-George Regional Library
3214 Pascagoula Street
Pascagoula, MS 39567

Jackson Metropolitan Library
301 North State Street
Jackson, MS 39201

Harriette Person Memorial Library
College Street
Port Gibson, MS 39150

Hattiesburg Public Library
723 Main Street
Hattiesburg, MS 39401

Laurel-Jones County Public Library
530 Commerce Street
Laurel, MS 39440

Jones County Junior College Library
Front Street
Ellisville, MS 39437

Texas

Deaf Smith County Library
211 East Fourth Street
Hereford, TX 79045

Rhoads Memorial Library
103 Southwest Second Street
Dimmitt, TX 79027

Swisher County Library
127 Southwest Second Street
Swisher County Memorial Building
Tulia, TX 79088

Gabie Betts Burton Memorial Library
217 S. Karney St.
Clarendon, TX 79226

Canyon Public Library
301 16th Street
Canyon, TX 79015

Austin Public Library
800 Guadalupe Street
Austin, TX 78768

Texas (continued)

Amarillo Public Library
413 East Fourth Street
Post Office Box 2172
Amarillo, TX 79189

Texas Nuclear Waste Programs Office
Sam Houston Office Building, Room 204
200 East 14th Street
Austin, TX 78711

Tulia Nuclear Waste Information Office
Griffith Estate Building
100 S.E. Second
Tulia, TX 79088

University of Texas General Library
Post Office Box P
Austin, TX 78712

Hereford Nuclear Waste Information Office
115 East First Street
Hereford, TX 79045

Utah

Moab Nuclear Waste Information Office
471 South Main Street No. 3
Moab, UT 84532

Monticello Nuclear Waste Information Office
San Juan County Courthouse
117 South Main Street, Room 12
Monticello, UT 84535

Grand County Public Library
25 South First Street East
Moab, UT 84532

Grand County High School Library
300 South 100 East
Moab, UT 84532

San Juan County Library
266 North Main Street
Monticello, UT 84535

Monticello High School Library
Media Center
55 North Second Street West
Monticello, UT 84535

San Juan County Library
50 West First Street South
Blanding, UT 84535

Mesa County Public Library
530 Grand Avenue
Grand Junction, CO 81501

Salt Lake City Public Library
2197 East 7000 South
Salt Lake City, UT 84121

University of Utah
Marriott Library
Salt Lake City, UT 84112

B.4 REFERENCES CITED IN THE EA FOR THE TUFF SITE

The references cited in the EA for the Yucca Mountain site are available for public review at the following locations:

Amargosa Valley Community Library
Star Route 15
Box 40-T
Amargosa Valley, NV 89020

Beatty Community Library
4th and Ward
P.O. Box 128
Beatty, NV 89003

Clark County Library
1401 E. Flamingo
Las Vegas, NV 89109

Lincoln County Library
P.O. Box 330
Pioche, NV 89043

Nevada State Library
401 N. Carson
Capitol Complex
Carson City, NV 89710

University of Nevada at Las Vegas
James R. Dickinson Library
4505 Maryland Parkway
Las Vegas, NV 89154

United States Department of Energy
Nevada Operations Office
Public Reading Room
2753 South Highland
Las Vegas, NV 89109

Law Library
Nye County Courthouse
P.O. Box 393
Tonopah, NV 89049

Nevada Legislative Council Bureau
Research Library
Legislative Building
Capitol Complex
Carson City, NV 89710

Northern Nevada Community College
Learning Resource Center
901 Elm Street
Elko, NV 89801

University of Nevada at Reno
Getchell Library
Reno, NV 89557

Washoe County Library
301 Center Street
Reno, NV 89502

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