Received with letter dtd 4/6/92

SAIC-91/8000

U.S. DEPARTMENT OF ENERGY

OCRWM

YUCCA MOUNTAIN

YUCCA MOUNTAIN
SITE CHARACTERIZATION
PROJECT

Report of Early Site Suitability Evaluation of the Potential Repository Site at Yucca Mountain, Nevada

January 1992

Technical & Management Support Services

CONTRACT NO. DE-AC08-87NV10576

SAIC®

SCIENCE APPLICATIONS INTERNATIONAL CORPORATION

102.8

Technical & Management Support Services
SCIENCE APPLICATIONS INTERNATIONAL CORPORATION

REPORT OF EARLY SITE SUITABILITY EVALUATION OF THE POTENTIAL REPOSITORY SITE AT YUCCA MOUNTAIN, NEVADA

JEAN L. YOUNKER, WILLIAM B. ANDREWS, GREGORY A. FASANO, C. CHARLES HERRINGTON, STEVEN R. MATTSON, ROBERT C. MURRAY, Science Applications International Corporation, Las Vegas, NV; LYNDEN B. BALLOU, MICHAEL A. REVELLI, Lawrence Livermore National Laboratory, Livermore, CA; ARTHUR R. DUCHARME, LES E. SHEPHARD, Sandia National Laboratories, Albuquerque, NM; WILLIAM W. DUDLEY, DWIGHT T. HOXIE, U.S. Geological Survey, Denver, CO; RICHARD J. HERBST, EDWARD A. PATERA; Los Alamos National Laboratory, Los Alamos, NM; BRUCE R. JUDD, Decision Analysis Company, Portola Valley, CA; JANET A. DOCKA, LARRY D. RICKERTSEN, Weston Technical Associates, Washington, DC;

Assisted by: JEREMY M. BOAK, Yucca Mountain Site Characterization Project Office, U.S. Department of Energy, Las Vegas, NV; JANE R. STOCKEY, Office of Geologic Disposal, U.S. Department of Energy, Washington, DC

JANUARY 1992

WORK PERFORMED UNDER CONTRACT NO. DE-AC08-87NV10576

DISCLAIMER

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

Page

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF TABLES

LIST OF TABLES (continued)

Report of Early Site Suitability Evaluation of the Potential Repository Site at Yucca Mountain, Nevada

EXECUTIVE SUMMARY

January 1992

EXECUTIVE SUMMARY

BACKGROUND

This study evaluated the technical suitability of Yucca Mountain, Nevada, as a potential site for a mined geologic repository for the permanent disposal of radioactive waste. In the judgment of the team conducting this evaluation, the presently available evidence continues to support the findings of the Environmental Assessment (EA) (DOE, 1986) that the site is suitable for site characterization. This evaluation, however, found that additional information is needed in specific areas before a final recommendation can be made regarding the suitability of the site for repository development.

The judgments presented in this report are those of the team that conducted this study, referred to as the "Core Team," and are not findings or conclusions made or endorsed by the U.S. Department of Energy (DOE). Rather, this report is being submitted to the DOE as one input to the DOE siting process set forth in DOE's General Siting Guidelines at Title 10, Part 960 of the Code of Federal Regulations (10 CFR Part 960). The Siting Guidelines establish criteria for selecting and evaluating the suitability of potential repository sites. The siting process involves characterization of the site and development and evaluation of repository and waste package designs to support site suitability evaluations. If the DOE determines that the site is suitable, a license application would then be prepared and submitted to the U.S. Nuclear Regulatory Commission. The overall process to be followed in siting and licensing a geologic repository was established in the Nuclear Waste Policy Act of 1982, and the amendment to this Act in 1987.

The DOE requested that this site suitability evaluation be undertaken early in the site characterization phase for the Yucca Mountain site and it is therefore referred to as the "Early Site Suitability Evaluation" (ESSE). The purpose of the ESSE was to determine if there is evidence of features or conditions that would render the Yucca Mountain site unsuitable for repository development. This is the second such evaluation for the Yucca Mountain site; a preliminary site suitability evaluation was completed as part of the site selection process, and its findings are reported in the EA. That evaluation, like the present one, was conducted according to DOE's Siting Guidelines in 10 CFR Part 960.

The Core Team that conducted this study was composed of technical personnel having expertise in each of the areas covered by the Siting Guidelines. The team included representatives from those organizations that are participating with the DOE in characterizing and evaluating the Yucca Mountain site. The Core Team members, in turn, drew on expertise both from within and from outside their organizations in completing this evaluation.

In performing the evaluation, the team was directed to consider all available site data and information, including that used in the EA, as well as information developed since the EA. This information included published and draft reports, internal memoranda, oral presentations, and written communications. On the basis of this information and a review of the EA site suitability findings, the team generated a set of recommendations for suitability findings that can be supported by available evidence and data. The team also identified issues that need to be resolved before final conclusions regarding the suitability of the site for repository development can be made.

The judgments presented in this report are the product of extensive study, deliberation, and debate by the Core Team. In making these judgments, the Core Team required that a consensus opinion be reached on each major site suitability finding or conclusion. Consequently, the major conclusions of the ESSE report are supported by every member of the Core Team.

To ensure that the evaluation was technically sound and logically consistent, the ESSE report underwent two formal reviews. The first review was performed by technical personnel within the Yucca Mountain Site Characterization Project (YMP) who were not involved in preparing the ESSE report and its site suitability evaluations. The second review was conducted by a panel of experts (university faculty members and private consultants) who have had minimal previous involvement with the geologic repository program. The report was then revised based on the comments and recommendations received from reviewers, and these revisions were subsequently reviewed and accepted by the reviewers. The comments of the outside peer review and the associated responses are provided in a companion document to this ESSE report (Younker et al., 1992).

RELATIONSHIP BETWEEN SITE SUITABILITY EVALUATIONS AND THE DECISION MAKING PROCESS

As stated above, this early site suitability evaluation provides input to DOE's ongoing siting process. Major elements of that process are represented in Figure E-1, along with their relationship to DOE decisions about the site.

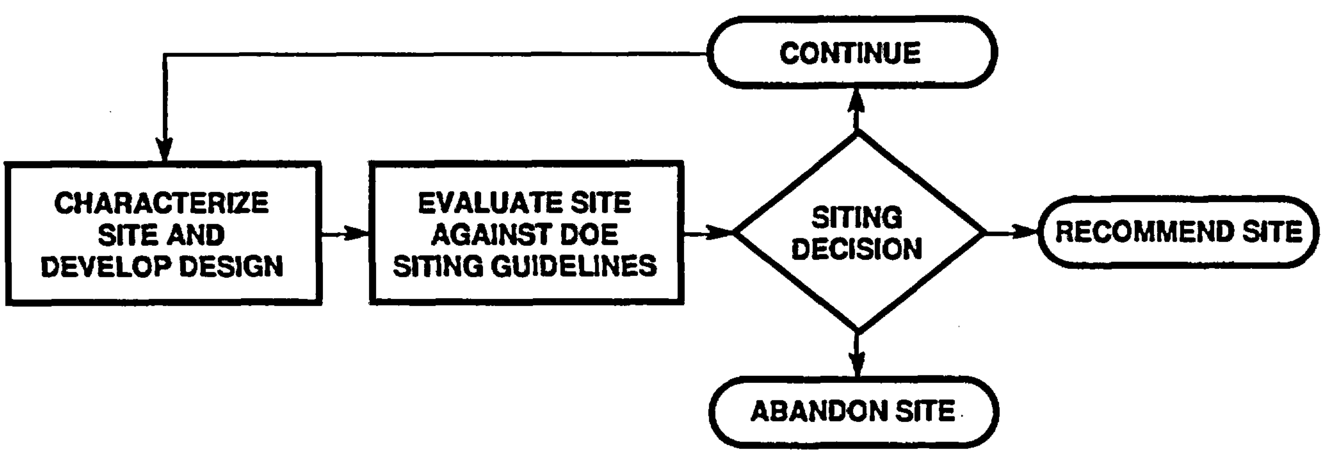


Figure E-1. The relationship of site suitability evaluations to repository design, site characterization, and DOE decisions about the site.

Site characterization and design development activities, which are represented in the first box, provide the information upon which DOE's site suitability evaluations and findings are based. Those suitability evaluations, which are made following the framework set forth in the DOE Siting Guidelines, are represented by the second box.

The diamond in the figure represents DOE siting decisions, such as whether to continue site characterization, to recommend the site as suitable for repository development, or to abandon the site as unsuitable. Technical suitability of the site is only one consideration in such decisions. The DOE may factor in many other considerations, such as the cost and delay incurred by additional site characterization, the adequacy of site information for design and licensing, or the advantages and risks of proceeding with Yucca Mountain versus abandoning it in favor of an alternate site. The conclusions given in this report do not constitute DOE siting decisions. Rather, the conclusions are technical recommendations to the DOE regarding the suitability of the Yucca Mountain site for continued site characterization and possible future development as a geologic repository.

OVERVIEW OF DOE GENERAL SITING GUIDELINES

As indicated above, this evaluation was based on the DOE's Siting Guidelines, which establish criteria to be considered when judging the suitability or unsuitability of sites for site characterization or repository development. The guidelines form a multilayered hierarchy, as depicted in Figure E-2. The first level of the hierarchy consists of two categories:

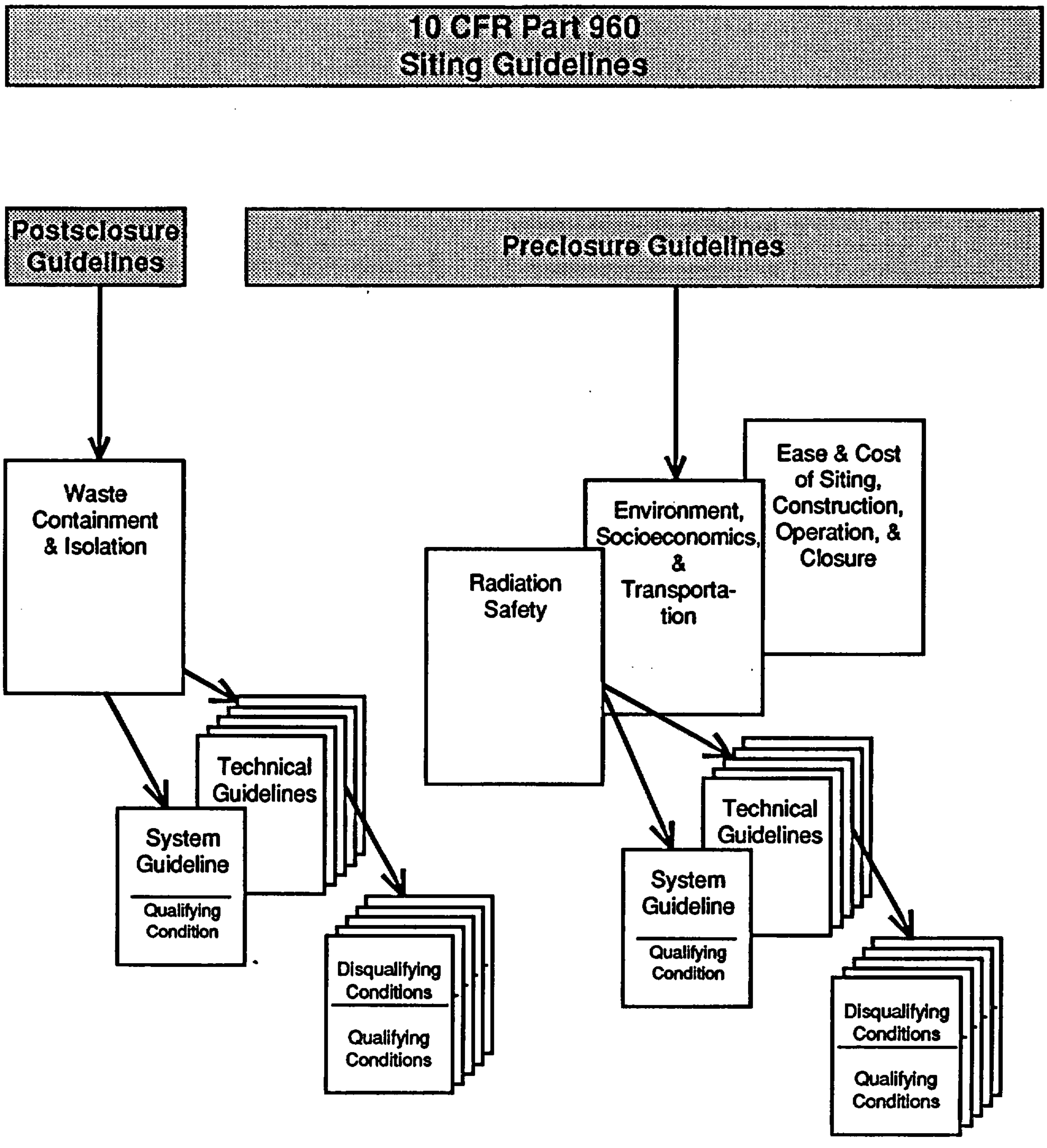
- Postclosure guidelines, which relate to the ability of the site to contain and isolate wastes after the repository is permanently closed
- Preclosure guidelines, which relate to characteristics that could affect the public, the environment, or workers during siting, construction, and operation of the repository before closure.

The Siting Guidelines specify that postclosure guidelines are of primary importance for evaluating site suitability while the preclosure guidelines are of secondary significance. This distinction, however, was not considered explicitly as part of the ESSE study.

There is only one postclosure guideline group, whereas the preclosure guidelines are grouped in decreasing order of importance for repository siting as follows:

1. Preclosure radiological safety
2. Environmental quality, socioeconomic impacts, and transportation
3. Ease and cost of siting, construction, operation, and closure.

Each postclosure and preclosure guideline is divided into system and technical guidelines. System guidelines address the expected performance of the total repository system with respect to the topic of the guideline. Each system guideline includes a set of technical guidelines that concern those specific features and conditions of the site that could affect repository performance.



SITEGUID.074/1-22-92

Figure E-2. Hierarchical Structure of the U.S. Department of Energy Siting Guidelines, 10 CFR Part 960.

The technical guidelines are subdivided into qualifying and disqualifying conditions. Although each technical guideline specifies at least one qualifying condition, not all technical guidelines identify disqualifying conditions. For a site to be considered suitable for repository development, it must satisfy all of the qualifying conditions and no disqualifying conditions can be present.

The postclosure guidelines are listed and described in Table E-1, and the preclosure guidelines are listed and described in Table E-2.

EVALUATION

The site suitability evaluation described in this report was based on the structure of the Siting Guidelines. The evaluations began at the lowest level of the guideline hierarchy. Using presently available site information and data, the Core Team assessed the site against each qualifying and disqualifying condition and developed conclusions for each technical guideline. The conclusions were then integrated to form a conclusion for each system guideline and, finally, combined to develop an overall conclusion for the site.

In accordance with the Siting Guidelines, conclusions about the site can be either that current information supports an unsuitability finding or that current information supports a suitability finding. An unsuitability finding means that (1) a disqualifying condition is present, or (2) a qualifying condition is not present. A suitability finding means that (1) a disqualifying condition is not present, or (2) a qualifying condition is present.

The Siting Guidelines specify two levels of suitability findings, depending on the likelihood that new information could change current conclusions about the site. These levels are designated "lower-level" and "higher-level" suitability findings in this report and are defined as follows:

Lower-Level Suitability Finding	A lower-level suitability finding can be supported when (1) a disqualifying condition does not appear to be present, but additional information could change the conclusion; or (2) a qualifying condition appears to be present, but additional information could change the conclusion, and thus, the site could subsequently be found to be unsuitable.
Higher-Level Suitability Finding	A higher-level suitability finding can be supported when (1) a disqualifying condition is not present and additional information is unlikely to change the conclusion; or (2) a qualifying condition is present and additional information is unlikely to change the conclusion. This finding would be supported if there is high confidence in the conclusion based on current information.

Table E-1. Postclosure Guideline Descriptions From the U.S. Department of Energy (DOE) Siting Guidelines in 10 CFR Part 960.

Guideline	Condition	Description
System Guideline	Qualifying	Postclosure performance meets regulatory standards
Technical Guidelines		
Geohydrology	Qualifying	Geohydrologic setting is compatible with waste containment and isolation
	Disqualifying	Ground-water travel time is less than 1,000 years along paths of likely and significant radionuclide travel
Geochemistry	Qualifying	Geochemical characteristics are compatible with waste containment and isolation
Rock Characteristics	Qualifying	Rock characteristics will accommodate thermal, chemical, mechanical, and radiation stresses
Climatic Changes	Qualifying	Future climate is not likely to lead to releases greater than regulatory limits
Erosion	Qualifying	Erosion is not likely to lead to releases greater than regulatory limits
	Disqualifying	Site conditions preclude 200 m overburden above the repository
Dissolution	Qualifying	Dissolution is not likely to lead to releases greater than regulatory limits
	Disqualifying	Active dissolution could result in loss of waste isolation

Table E-1. Postclosure Guideline Descriptions From the U.S. Department of Energy (DOE) Siting Guidelines in 10 CFR Part 960. (continued)

Guideline	Condition	Description
Tectonics	Qualifying	Future tectonic processes and events are not likely to violate release limits
	Disqualifying	Fault movements are expected to cause loss of waste isolation
Human Interference		
Natural Resources	Qualifying	Natural resources are not likely to cause interference activities that could lead to releases greater than regulatory limits
	Disqualifying	1. Previous exploration has created significant pathways 2. Activities outside the controlled area are expected to lead to loss of waste isolation
Site Ownership and Control	Qualifying	DOE can obtain ownership, surface and subsurface rights, and control of access

Table E-2. Preclosure Guideline Descriptions From the U.S. Department of Energy (DOE) Siting Guidelines in 10 CFR Part 960.

Guideline	Condition	Description
		PRECLOSURE RADIOLOGICAL SAFETY
System Guideline	Qualifying	Preclosure exposures meet applicable safety standards
Technical Guidelines		
Population Density and Distribution	Qualifying	1. Doses to highly populated areas are not likely to exceed small fraction of limits
		2. Dose to any member of public in unrestricted area is not likely to exceed limits
	Disqualifying	1. Site located in a highly populated area
		2. Site located adjacent to a one-square-mile area with population greater than 1,000
		3. DOE cannot develop emergency preparedness program
Site Ownership and Control	Qualifying	DOE can obtain ownership, surface and subsurface rights, and control of access
Meteorology	Qualifying	Meteorological conditions are not likely to lead to releases above limits
Offsite Installations and Operations	Qualifying	Effects from offsite facilities can be accommodated and will not lead to releases above limits
	Disqualifying	Irreconcilable conflicts with atomic energy defense activities are expected

Table E-2. Preclosure Guideline Descriptions From the U.S. Department of Energy (DOE) Siting Guidelines in 10 CFR Part 960. (continued)

Guideline	Condition	Description
ENVIRONMENTAL QUALITY - SOCIOECONOMIC IMPACTS - TRANSPORTATION		
System Guideline	Qualifying	Public and environment are adequately protected
Technical Guidelines		
Environmental Quality	Qualifying	Environmental quality is adequately protected
	Disqualifying	1. Environment cannot be adequately protected or impacts acceptably mitigated
		2. Site is located within protected area
		3. Irreconcilable conflicts are expected with a protected area
Socioeconomic Impacts	Qualifying	Impacts can be offset by reasonable mitigation or compensation
	Disqualifying	Significant reduction in water quality/quantity at offsite sources is expected
Transportation	Qualifying	1. Access routes will not cause irreconcilable conflicts with a protected area
		2. Routes can be designed with reasonably available technology
		3. No extreme performance standards are required
		4. No unacceptable risks or environmental impacts are expected

Table E-2. Preclosure Guideline Descriptions From the U.S. Department of Energy (DOE) Siting Guidelines in 10 CFR Part 960. (continued)

Guideline	Condition	Description
EASE AND COST OF SITING, CONSTRUCTION, OPERATION, AND CLOSURE		
System Guideline	Qualifying	Repository siting, construction, operation, and closure will be feasible using reasonably available technology
Technical Guidelines		
Surface Characteristics	Qualifying	Can be accommodated using reasonably available technology
Rock Characteristics	Qualifying	1. Thickness and lateral extent are adequate 2. No undue hazards to personnel are expected 3. Reasonably available technology will be adequate
	Disqualifying	Presence of significant risk to health and safety of personnel taking into account possible mitigation using reasonably available technology
Hydrology	Qualifying	1. Setting is compatible with repository development 2. Liners and seals will function as designed 3. Reasonably available technology will be adequate
	Disqualifying	Expected ground-water conditions require engineering measures beyond reasonably available technology

Table E-2. Preclosure Guideline Descriptions From the U.S. Department of Energy (DOE) Siting Guidelines in 10 CFR Part 960. (continued)

Guideline	Condition	Description
Tectonics	Qualifying	Expected tectonic activity can be accommodated with reasonably available technology
	Disqualifying	Expected fault movement will require engineering measures beyond reasonably available technology

A higher-level suitability finding for a particular disqualifying or qualifying condition does not necessarily mean that all remaining uncertainties regarding the condition have been resolved. Rather, a higher-level suitability finding means that gaining additional information to resolve the remaining uncertainties is unlikely to change the present conclusion about the suitability of the site.

The terms "likely" and "unlikely" are used in the DOE Siting Guidelines in a qualitative sense in relation to making lower-level and higher-level suitability findings. Consequently, an integral part of the deliberative process used by the Core Team to achieve consensus was to develop appropriate meanings for these terms in the context of each qualifying and disqualifying condition. The Core Team generally interpreted "likely" in the quantitative sense of probability or likelihood. In conducting their evaluations, the team members, therefore, estimated the likelihood that a condition would be present at the site and, additionally, the likelihood necessary to support the suitability findings specified by 10 CFR Part 960. In making such judgments, the team members also factored in their opinions on the relative importance of the particular condition in relation to site performance. Thus, each judgment of the team members considered the nature of the condition, the likelihood of its being present, and the confidence required in order to reach a suitability finding. The individual judgments were then consolidated into a Core Team consensus position.

If each Core Team member judged, at a minimum, that current information does not indicate that the site is unsuitable, then the consensus position was that at least a lower-level suitability finding could be supported. If, in addition, each team member judged that future information will be unlikely to change the current conclusion regarding site suitability, then a higher-level suitability finding could be supported. If, on the other hand, a single Core Team member favored a lower-level finding, then only a lower-level finding could be supported. This method of reaching consensus ensured that higher-level suitability findings could be supported only by unanimous agreement among the Core Team.

Because findings on the Siting Guidelines are the prerogative of the DOE, the Core Team did not make formal suitability findings. Rather, the Core Team reached consensus opinions concerning whether available evidence was sufficient to support a particular level of finding for each disqualifying and qualifying condition and for each system and technical guideline.

SUMMARY OF EVALUATION RESULTS

Considerable data and analyses have become available since the EA for the Yucca Mountain site was issued in 1986. New information has been obtained from surface-based studies, ongoing monitoring activities, and laboratory studies, as well as from reanalysis of data gathered before the EA using new analysis techniques. The consensus of the Core Team is that the new information corroborates the findings of the EA that the site is suitable for characterization. In some cases, the evidence supports stronger findings regarding suitability for repository development. The consensus findings by the Core Team for each of the guidelines are summarized below.

Postclosure Guideline Results

The results of the evaluation of the Postclosure Guidelines are summarized in Table E-3 and discussed in the following sections.

Disqualifying Conditions. The Core Team concluded that the current information supports a finding that none of the disqualifying conditions prescribed in the Postclosure Guidelines are present or likely to be present at the Yucca Mountain site. Furthermore, the consensus was that additional information is not likely to change the suitability findings for any of the postclosure disqualifying conditions, except, possibly, for the Postclosure Geohydrology Technical Guideline. The disqualifying condition for the Geohydrology Guideline is concerned with the time required for ground water to travel 5 km from the repository boundary along pathways that could allow significant releases of radionuclides. Current geohydrologic evidence does not preclude the presence of a small number of fast flow pathways that could lead to travel times shorter than mandated by the guidelines. Therefore, only a lower-level suitability finding is supported for this guideline.

Higher-level suitability findings are supported for the disqualifying conditions for the Erosion, Dissolution, Tectonics, and Natural Resources Guidelines. The bases for supporting these higher-level findings are as follows:

- Erosion Guideline — Site conditions will allow the underground facility to be placed at a depth of 200 m or more.
- Dissolution Guideline — The minerals composing the potential host rock and surrounding rock units are not expected to undergo significant dissolution during the first 10,000 years after closure of the repository.
- Tectonics Guideline — No credible scenarios were identified in which fault movement or ground motion in the underground facility could directly cause loss of waste isolation.

Table E-3. Postclosure Guideline Evaluation Results[a,b]

Guideline	Disqualifying Condition	Qualifying Condition
System	Not applicable[c]	Condition is likely to be met (LLF)[d]
Technical		
Geohydrology	Condition is not likely to be present (LLF)	Condition is likely to be met (LLF)
Geochemistry	Not applicable	Condition is likely to be met (LLF)
Rock Characteristics	Not applicable	Condition is likely to be met (LLF)
Climatic Changes	Not applicable	Condition is likely to be met (LLF)
Erosion	Condition is not present and future information is unlikely to change conclusion (HLF)[e]	Condition is met and future information is unlikely to change conclusion (HLF)
Dissolution	Condition is not present and future information is unlikely to change conclusion (HLF)[f]	Condition is met and future information is unlikely to change conclusion (HLF)[f]
Tectonics	Condition is not present and future information is unlikely to change conclusion (HLF)	Condition is likely to be met (LLF)
Human Interferance		
Natural Resources	Conditions 1 and 2 not present and future information is unlikely to change conclusion (HLF)	Condition is likely to be met (LLF)
Site Ownership and Control	Not applicable	Condition is met and future information is unlikely to change conclusion (HLF)

[a]The results presented here are supported by every member of the Core Team.
[b]See Table E-1 for descriptions of Postclosure Guideline.
[c]Not applicable: 10 CFR Part 960 provides no disqualifying condition associated with this guideline.
[d]LLF: Lower-level suitability finding is supported.
[e]HLF: Higher-level suitability finding is supported.
[f]The Environmental Assessment (DOE, 1986) reported a higher-level suitability finding on this guideline.

- Natural Resources Guideline — Available evidence indicates that previous mining or mineral exploration activities have not created significant pathways from the potential repository to the accessible environment, and no credible scenarios have been identified through which present-day mining activities outside the controlled area could lead to loss of waste isolation.

Qualifying Conditions. The Core Team concluded that lower-level suitability findings can continue to be supported for the qualifying conditions of all of the Postclosure Guidelines. Furthermore, the team has high confidence that new information is unlikely to change the conclusion that the qualifying conditions are met for the Erosion, Dissolution, and Site Ownership and Control Guidelines. Thus, the Core Team concluded that higher-level suitability findings can be supported for the qualifying conditions for these guidelines.

The bases for supporting these higher-level findings are as follows:

- Erosion Guideline — No credible erosion scenarios were identified that would be likely to lead to radionuclide releases greater than allowable.

- Dissolution Guideline — No credible dissolution scenarios were identified that would be likely to lead to radionuclide releases greater than allowable.

- Site Ownership and Control Guideline — A process for land withdrawal exists, and no unusual impediments are anticipated to obtaining complete ownership and control.

The Core Team continues to support a lower-level suitability finding for the Postclosure System Guideline. Aqueous-phase radionuclide releases are expected to meet the Environmental Protection Agency (EPA) release limits by a significant margin. There remain, however, unresolved issues with regard to possible gaseous-phase carbon-14 releases to the accessible environment. These issues include uncertainties in the amount of carbon-14 available to be released as carbon dioxide gas from the waste package and in the ability of the unsaturated zone to retard gaseous-phase carbon-14 transport to the accessible environment above the repository. The potential health hazards in terms of doses to members of the public from releases of gaseous carbon-14 are expected to be negligible, however, which possibly reflects an inconsistency between the regulatory limits and the actual hazard.

Preclosure Guideline Results

The results of the evaluation of the Preclosure Guidelines are summarized in Table E-4 and discussed in the following sections.

Radiological Safety Guidelines. The Core Team concluded that higher-level suitability findings can be supported for both of the two disqualifying conditions for the radiological safety guideline. The basis for this conclusion is the following:

Table E-4. Preclosure Guideline Evaluation Results[a,b]

Guideline	Disqualifying Condition	Qualifying Condition
	PRECLOSURE RADIOLOGICAL SAFETY	
System	Not applicable[c]	Condition is likely to be met (LLF)[d]
Technical		
Population Density and Distribution	Conditions 1, 2, and 3 are not present and future information is unlikely to change conclusions (HLF)[e,f]	Condition is met and future information is unlikely to change conclusion (HLF)
Site Ownership and Control	Not applicable	Condition is met and future information is unlikely to change conclusion (HLF)
Meteorology	Not applicable	Condition is met and future information is unlikely to change conclusion (HLF)
Offsite Installations and Operations	Condition is not present and future information is unlikely to change conclusion (HLF)	Condition is likely to be met (LLF)
	ENVIRONMENTAL QUALITY - SOCIOECONOMIC IMPACTS - TRANSPORTATION	
System	Not applicable	Condition is likely to be met (LLF)[f]
Technical		
Environmental Quality	Conditions 1 and 3 are not likely to be present (LLF) Condition 2 is not present and future information is unlikely to change conclusion (HLF)	Condition is likely to be met (LLF)
Socioeconomic Impacts	Condition is not likely to be present (LLF)	Condition is likely to be met (LLF)
Transportation	Not applicable	Condition is likely to be met (LLF)

Table E-4. Preclosure Guideline Evaluation Results[a,b] (continued)

Guideline	Disqualifying Condition	Qualifying Condition
EASE AND COST OF SITING, CONSTRUCTION, OPERATION, AND CLOSURE		
System	Not applicable	Condition is likely to be met (LLF)
Technical		
Surface Characteristics	Not applicable	Condition is met and future information is unlikely to change conclusion (HLF)
Rock Characteristics	Condition is not present and future information is unlikely to change conclusion (HLF)	Condition is likely to be met (LLF)
Hydrology	Condition is not present and future information is unlikely to change conclusion (HLF)	Condition is met and future information is unlikely to change conclusion (HLF)
Tectonics	Condition is not present and future information is unlikely to change conclusion (HLF)	Condition is likely to be met (LLF)

[a]The results presented here are supported by every member of the Core Team.
[b]See Table E-2 for descriptions of Preclosure Guideline.
[c]Not applicable: 10 CFR Part 960 provides no disqualifying condition associated with this guideline.
[d]LLF: Lower-level suitability finding is supported.
[e]HLF: Higher-level suitability finding is supported.
[f]Higher-level suitability findings on disqualifying conditions 1 and 2 are reported in the Environmental Assessment (DOE, 1986).

- Population Density and Distribution Guideline — The nearest highly populated area is about 85 miles from the site, and the nearest one-square-mile area with a population greater than 1,000 is about 20 miles from the proposed surface facilities; an adequate Emergency Preparedness Plan can be prepared and approved.

- Offsite Installations and Operations Guideline — Activities associated with repository siting, construction, operation, and closure are not expected to result in irreconcilable conflicts with atomic energy defense activities.

Likewise, higher-level suitability findings can be supported for the qualifying conditions for the Population Density and Distribution, Site Ownership and Control, and Meteorology Guidelines. The basis for this conclusion is the following:

- Population Density and Distribution Guideline — The population distribution is favorable for protecting the public from unacceptable radiological exposures and is unlikely to constrain facility design.

- Site Ownership and Control Guideline — A process for land withdrawal is available, and no unusual impediments are anticipated to obtaining complete ownership and control of the site.

- Meteorology Guideline — The prevailing conditions reduce the probability of preferential airborne transport, and the likelihood of severe weather impacting operations is extremely low.

Lower-level suitability findings continue to be supported for the qualifying conditions for the Radiological Safety System Guideline and for the technical guideline for Offsite Installations and Operations. The Core Team concluded that more mature repository design and site-specific release calculations are needed to determine if higher-level suitability findings can be supported for these guidelines.

There is already considerable practical experience in the design of nuclear facilities, such as nuclear power plants and spent-fuel handling facilities, to meet radiological safety standards. Much of the technology to be applied to the repository was developed for service in reprocessing facilities where particulate and gaseous releases are controlled. By nature, the repository environment should be less challenging to effluent control systems than facilities that reprocess spent fuel. Such experience indicates that, as long as factors such as site meteorology and local population distribution are accounted for in the facility design, there is high confidence that radiological safety standards can be met.

Environmental Quality, Socioeconomic Impacts, and Transportation Guidelines. Three disqualifying conditions are associated with the Environmental Quality Guideline:

1. the environment cannot be protected or impacts mitigated;
2. repository facilities would be located within a protected area; and
3. irreconcilable conflicts are expected with protected lands.

The Core Team concluded that a higher-level suitability finding can be supported for the second disqualifying condition. The basis for this conclusion is as follows:

- Environmental Quality Guideline — The DOE is unlikely to choose to locate the repository facilities in a National Park, National Wildlife Refuge, or similar protected area. (Disqualifying condition 2)

Although available evidence suggests that potential environmental impacts and conflicts can be mitigated, the Core Team concluded that additional information is needed to support a higher-level suitability finding for disqualifying condition 1 for the Environmental Quality Guideline. There also is currently insufficient information to determine adequately the potential environmental impacts, the mitigation measures that may be needed, and the potential for future irreconcilable conflicts with federally protected lands (disqualifying condition 3 for the Environmental Quality Guideline). Likewise, for the Socioeconomic Impacts Guideline, additional information is needed to support the higher-level suitability finding for the disqualifying condition that water quality or quantity will not be significantly degraded, or that impacts can be mitigated.

The Core Team concluded that available information continues to support the lower-level suitability findings reported in the EA for the qualifying conditions for the Environmental Quality, Socioeconomic Impacts, and Transportation Guidelines. The Core Team concluded that the current lack of specific information about environmental impacts and the mitigation measures that may be needed does not allow a higher-level suitability finding to be supported for the qualifying condition for the Environmental Quality Guideline at this time. Similarly, additional information is needed from the process of analysis, planning, and consultation with affected parties specified in the Socioeconomic Impacts Guideline before a higher-level suitability finding can be supported for the Socioeconomic Impacts qualifying condition. The mitigation and compensation measures needed to avoid significant adverse social or economic impacts in communities and surrounding regions will, in part, be determined through this process. For the Transportation Guideline, additional information about potential risks to the public due to transportation, as well as information about potential environmental impacts and packaging technologies, is needed to support a higher-level suitability finding for the qualifying condition.

Ease and Cost of Siting, Construction, Operation, and Closure Guidelines. The Core Team concluded that higher-level suitability findings can be supported for all the disqualifying conditions in this category on the basis of the following:

- Rock Characteristics Guideline — Experience in materials with similar rock properties indicates that reasonably available technology will be adequate to ensure worker health and safety.

- Hydrology Guideline — Currently available engineering measures are considered more than adequate to prevent disruption of construction and operation because of ground-water conditions.

- Tectonics Guideline — Presently available knowledge of past earthquakes and fault locations, and current design technology indicate that tectonic hazards can be accommodated with reasonably available technology.

The Core Team's decision to support a higher-level suitability finding for the Preclosure Tectonics disqualifying condition is in keeping with the idea that disqualifying conditions are intended to represent site features and conditions that can be evaluated earlier in the siting process without extensive data gathering or complex analysis. In contrast, the team concluded that current evidence supports a lower-level suitability finding for the qualifying condition for Preclosure Tectonics, which is worded similarly to the disqualifying condition. This is because more data and analysis are generally required to determine whether a site meets a qualifying condition. Although ground-motion and surface-rupture conditions on which repository designs are to be based are not expected to exceed the ability of reasonably available technology to accommodate them, those seismic conditions are not yet known well enough to support a higher-level suitability finding for the qualifying condition.

The Core Team also concluded that higher-level suitability findings could be supported for the qualifying conditions for surface characteristics and hydrology. The bases for these conclusions are as follows:

- Surface Characteristics Guideline — Standard drainage control measures are considered to be adequate to protect surface and underground facilities from hazards due to flooding.

- Hydrology Guideline — No surface water systems are present to flood the repository or compromise shaft/ramp liners and seals, and transient runoff can be handled adequately with standard drainage control measures.

Potential hazards from surface topography, flooding, rock stability, seismic conditions, or ground-water problems in the underground facility are expected to be mitigatable using standard engineering methods that have been applied and proven elsewhere in similar facilities.

A question remains about the adequacy of the thickness and lateral extent of the potential host rock to accommodate the underground repository facilities. There may be physical constraints on the location of facilities, and changes in the design basis for acceptable heat generation rates from emplaced waste could place additional demands on the amount of host rock needed. Although available evidence continues to support a lower-level suitability finding for the qualifying condition for Preclosure Rock Characteristics, new information could change this conclusion, and thus, the Core Team concluded that a higher-level finding could not be supported at this time.

RECOMMENDATIONS

Based on ESSE results, the Core Team recommends the following actions:

Resolve Issues. The Core Team recommends that technical issues be resolved for those guidelines for which only lower-level suitability findings can be supported with presently available information (see Tables E-3 and E-4). For example, a strategy is needed for dealing with the possible releases of gaseous carbon-14 to the accessible environment. Elements of this strategy could include (1) improving estimates of the inventory of carbon-14 in emplaced waste that could be available for release, (2) investigating engineered-barrier designs to mitigate possible releases of gaseous carbon-14, and (3) interacting with the EPA during their efforts to revise the standards for postclosure containment.

Document Resolution of Issues. The Core Team also recommends that formal steps be taken to document and close resolved issues. Closure may be appropriate for issues where further information or testing is unlikely to change the current conclusion about the suitability of the site. One method of closure would be for the DOE to adopt the evaluations of this report as formal suitability findings. Another would be to prepare position papers that document the basis for resolving issues, either on the basis of the material presented in this report or on further evaluation by the DOE. A third approach, which is applicable to anticipated licensing issues, might be to prepare issue resolution reports, as proposed in the Site Characterization Plan (DOE, 1988a).

Prioritize Proposed Tests. During this site suitability evaluation, the Core Team identified areas in which additional site information is needed before higher-level findings can be supported. This evaluation did not, however, formally assess the availability, reliability, cost, or value of specific tests and site characterization activities that might be performed to obtain the needed information. The Core Team recommends that a systematic approach be developed to assess these factors and to establish testing priorities based on the early site suitability evaluation results.

Report of Early Site Suitability Evaluation of the Potential Repository Site at Yucca Mountain, Nevada

SECTION 1: INTRODUCTION

January 1992

1.0 INTRODUCTION

1.1 PURPOSE AND BACKGROUND OF THE EARLY SITE SUITABILITY EVALUATION

This study evaluated the technical suitability of Yucca Mountain, Nevada, as a potential site for a mined geologic repository for the permanent disposal of radioactive waste. The evaluation was conducted primarily to determine early in the site characterization program if there are any features or conditions at the site that indicate it is unsuitable for repository development. A secondary purpose was to determine the status of knowledge in the major technical areas that affect the suitability of the site. This early site suitability evaluation (ESSE) was conducted by a team of technical personnel at the request of the Associate Director of the U.S. Department of Energy (DOE) Office of Geologic Disposal, a unit within the DOE's Office of Civilian Radioactive Waste Management.

The Yucca Mountain site has been the subject of such evaluations for over a decade. In 1983, the site was evaluated as part of a screening process to identify potentially acceptable sites. The site was evaluated in greater detail and found suitable for site characterization as part of the Environmental Assessment (EA) (DOE, 1986) required by the Nuclear Waste Policy Act of 1982 (NWPA). Additional site data were compiled during the preparation of the Site Characterization Plan (SCP) (DOE, 1988a). This early site suitability evaluation has considered information that was used in preparing both documents, along with recent information obtained since the EA and SCP were published. This body of information is referred to in this report as "current information" or "available evidence."

1.2 APPROACH TO THE EARLY SITE SUITABILITY EVALUATION

Figure 1-1 illustrates the ongoing siting process, which includes site characterization, repository design, and site suitability evaluation. The conclusions and recommendations in this early site suitability report provide input to the DOE's evaluation of site suitability, represented by the box near the center of the diagram. Site data and repository design information, which are provided by site characterization and design activities (represented by the left box), provide the basis for the evaluation. This early site suitability evaluation was conducted using the DOE Siting Guidelines, promulgated at Title 10, Part 960, of the Code of Federal Regulations (10 CFR Part 960). These guidelines establish criteria for selecting and evaluating the suitability of potential repository sites.

The DOE could use the results of this evaluation to make findings about site suitability and to identify critical suitability issues to be resolved. These results may be important considerations in making decisions, such as whether to continue site characterization (or other activities) and whether to recommend the site for development of a repository or to abandon it. Such decisions about the site are represented by the diamond on the right side of Figure 1-1. Note from the feedback loop in the figure that suitability evaluations might be repeated throughout the DOE siting process until it is determined that the site either is suitable for repository development or unsuitable and should be abandoned. In order for the site to be found

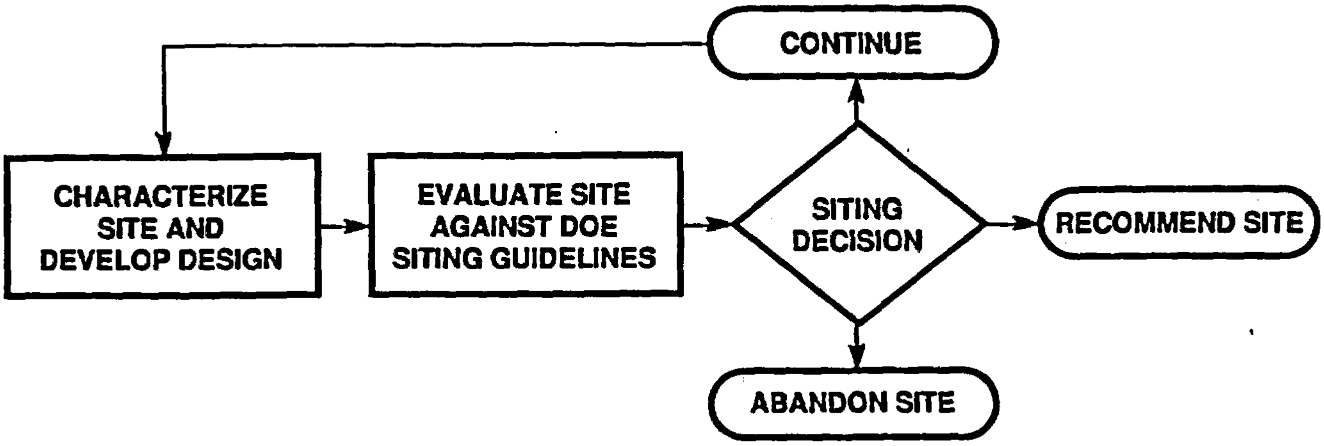


Figure 1-1. The relationship of site suitability evaluations to repository design, site characterization, and DOE decisions about the site.

suitable, appropriate findings must be made for all of the applicable criteria specified in the DOE Siting Guidelines. According to the NWPA, the DOE must then submit a license application to the U.S. Nuclear Regulatory Commission (NRC).

There is an important distinction between a DOE finding (represented by the center box) that the site is technically suitable and a DOE decision (represented by the diamond) to cease further work and either recommend the site for repository development or abandon it. The distinction is made because those who make programmatic decisions will generally consider additional factors that may not have been considered in a technical suitability evaluation. Additional factors might include the following:

- Motivations for testing other than determining site suitability (e.g., gathering data for repository design or licensing, confirming performance estimates, or providing additional assurance to review boards or other parties)
- Availability of reliable tests to provide needed information
- Judgments about the value of additional work relative to associated costs and delays
- Specific requirements for testing or other activities, such as developing an environmental impact statement (EIS).

Because such factors may not be considered in the site suitability evaluation, the particular conclusions reached in this report do not necessarily imply DOE decisions about the site or about future work. For example, assume that DOE makes a finding that the rock characteristics at the site are likely to meet waste isolation and containment requirements and that further information is unlikely to change this conclusion. These findings do not necessarily imply stopping all testing related to rock characteristics because data from such tests may be essential to completing the repository design.

This early site suitability evaluation is part of the evaluation represented by the center box in Figure 1-1. This evaluation was conducted by a Core Team composed of project participants and contractors to the DOE, rather than by the DOE itself. Because findings on DOE's Siting Guidelines are the prerogative of the DOE, the Core Team did not make formal suitability findings. Instead, the Team determined what conclusions about site suitability can be supported by available data. The members of the Core Team also identified issues that they believe should be resolved before making final conclusions on site suitability.

The approach the Core Team followed in reaching its conclusions is explained in the next six subsections. The first provides an overview of the DOE Siting Guidelines, and the second subsection explains the types of findings specified in the guidelines. Together, these two subsections provide the explanation essential to understanding the conclusions and recommendations in this report. The structure of the guidelines provided the structure for the evaluations presented in this report. The third subsection lists the findings made in the Environmental Assessment (DOE, 1986). The fourth details the step-by-step approach used to evaluate site suitability according to the guidelines. The fifth subsection identifies the members of the team that conducted the evaluation, and the sixth explains how the evaluation and report were reviewed.

1.2.1 Overview of the DOE General Siting Guidelines (10 CFR Part 960)

The DOE General Siting Guidelines in 10 CFR Part 960 identify factors to be considered when judging the suitability or unsuitability of a site for repository development. They are consistent with the U.S. Nuclear Regulatory Commission (NRC) Technical Criteria found in 10 CFR Part 60, and they incorporate requirements set by the NRC for the performance of the site. They are also consistent with the generally applicable standards established by the U.S. Environmental Protection Agency (EPA) for radiological protection of public health and safety (40 CFR Part 191).

In some instances, the Siting Guidelines cite specific measures and criteria for performance of the site:

> "A site shall be disqualified if the pre-waste-emplacement groundwater 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." (Postclosure Geohydrology Guideline)

In other instances, quantitative criteria are not provided, but the guidelines still focus attention on features and conditions that could affect the site's ability to isolate and contain waste or the safe operation of facilities before closure:

"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." (Preclosure Offsite Installations and Operations Guideline)

Preclosure and Postclosure Guidelines. This evaluation was based on the set of Siting Guidelines that establish criteria to be considered when judging the suitability or unsuitability of a site for site characterization or repository development. The guidelines form a multilayered hierarchy, as depicted in Figure 1-2. The first level of the hierarchy consists of two categories:

- Postclosure Guidelines, which relate to the ability of the site to contain and to isolate waste after the repository is permanently closed

- Preclosure Guidelines, which relate to characteristics that could affect the public, the environment, or workers during siting, construction, and operation of the repository before closure.

The Siting Guidelines specify that Postclosure Guidelines are of primary importance for evaluating site suitability while the Preclosure Guidelines are of secondary significance. This distinction, however, was not considered explicitly as part of this evaluation.

The Preclosure Guidelines are grouped in decreasing order of importance for repository siting as follows:

1. Preclosure Radiological Safety
2. Environmental Quality, Socioeconomic Impacts, and Transportation
3. Ease and Cost of Siting, Construction, Operation, and Closure.

The Postclosure Guideline and the three Preclosure Guidelines are divided into System and Technical Guidelines. System Guidelines address the expected performance of the total repository system, including both its natural and engineered components. For example, the Postclosure System Guideline focuses on long-term protection of public health and safety and the regulatory standards set to ensure waste isolation and containment:

"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..." (Postclosure System Guideline)

Similarly, the System Guideline for Preclosure Radiological Safety identifies the requirements for protection of the public and repository workers from exposure to radioactivity in the preclosure period. The System Guideline for Environmental Quality, Socioeconomic Impacts, and Transportation focuses on the need to protect the public and the environment from the hazards posed by the disposal of radioactive waste. The System Guideline for Ease and Cost of Siting, Construction, Operation, and Closure specifies the requirement for reasonable availability of technology for those activities.

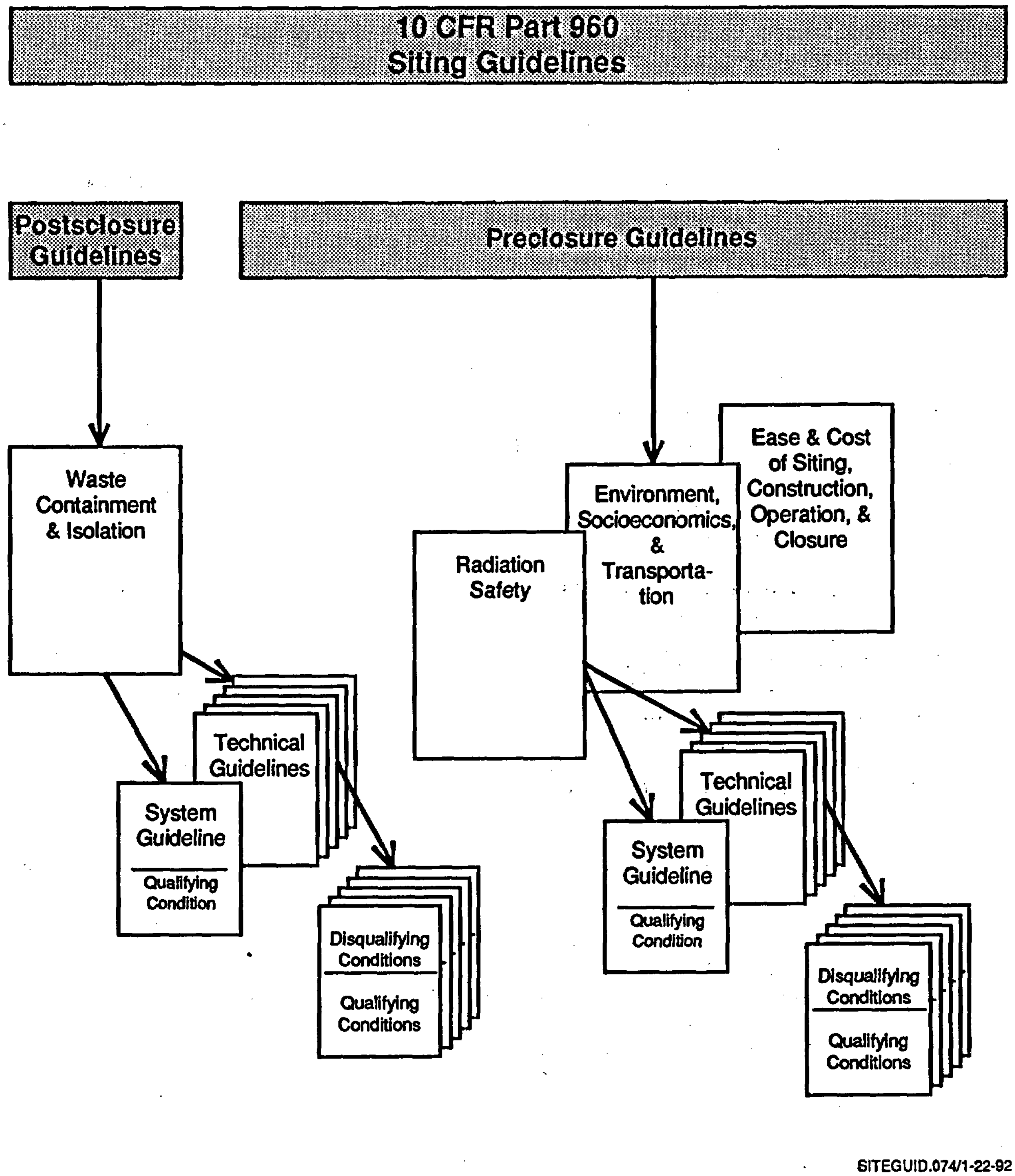


Figure 1-2. Hierarchical Structure of the U.S. Department of Energy Siting Guidelines, 10 CFR Part 960.

Technical Guidelines. Associated with each system guideline is a group of technical guidelines that address the specific characteristics of the site that may affect repository performance. These specify requirements on the features and conditions at the site that are intended to ensure that the broad requirements defined in the system guidelines are met. Each technical guideline, therefore, identifies factors regarding a particular category of site characteristics (e.g., geohydrology, geochemistry, and rock characteristics) to be considered in the evaluation of the site against the broad requirements for that group.

Qualifying and Disqualifying Conditions. The technical guidelines are subdivided into disqualifying and qualifying conditions. All technical guidelines have at least one qualifying condition, but a technical guideline need not have any disqualifying conditions. The Siting Guidelines indicate that the site should be disqualified if evidence supports a finding by the DOE that any disqualifying condition exists or any qualifying condition cannot be met.

In most cases, the qualifying conditions require that site characteristics allow the system guideline to be met. For example, the qualifying condition for Postclosure Geohydrology is compatibility with waste containment and isolation and compliance with system performance requirements:

> "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 ...[the system guideline] and (2) the requirements specified in ...[NRC's performance objectives] for radionuclide releases from the engineered-barrier system using reasonably available technology." (Postclosure Geohydrology qualifying condition)

The disqualifying condition for this same technical guideline places a requirement on a specific characteristic of the site:

> "A site shall be disqualified if the pre-waste-emplacement groundwater 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." (Postclosure Geohydrology disqualifying condition)

Some guidelines are quantitative and some are qualitative, but the focus of all is on the site features and conditions that could affect the ability of the site to isolate and contain waste or the safe operation of facilities before closure. Table 1-1 summarizes and describes the Postclosure Guidelines, while Table 1-2 presents the same information for the Preclosure Guidelines.

Table 1-1. Postclosure Guideline Descriptions From the U.S. Department of Energy (DOE) Siting Guidelines in 10 CFR Part 960.

Guideline	Condition	Description
System Guideline	Qualifying	Postclosure performance meets regulatory standards
Technical Guidelines		
Geohydrology	Qualifying	Geohydrologic setting is compatible with waste containment and isolation
	Disqualifying	Ground-water travel time is less than 1,000 years along paths of likely and significant radionuclide travel
Geochemistry	Qualifying	Geochemical characteristics are compatible with waste containment and isolation
Rock Characteristics	Qualifying	Rock characteristics will accommodate thermal, chemical, mechanical, and radiation stresses
Climatic Changes	Qualifying	Future climate is not likely to lead to releases greater than regulatory limits
Erosion	Qualifying	Erosion is not likely to lead to releases greater than regulatory limits
	Disqualifying	Site conditions preclude 200 m overburden above the repository
Dissolution	Qualifying	Dissolution is not likely to lead to releases greater than regulatory limits
	Disqualifying	Active dissolution could result in loss of waste isolation

Table 1-1. Postclosure Guideline Descriptions From the U.S. Department of Energy (DOE) Siting Guidelines in 10 CFR Part 960. (continued)

Guideline	Condition	Description
Tectonics	Qualifying	Future tectonic processes and events are not likely to violate release limits
	Disqualifying	Fault movements are expected to cause loss of waste isolation
Human Interference		
Natural Resources	Qualifying	Natural resources are not likely to cause interference activities that could lead to releases greater than regulatory limits
	Disqualifying	1. Previous exploration has created significant pathways
		2. Activities outside the controlled area are expected to lead to loss of waste isolation
Site Ownership and Control	Qualifying	DOE can obtain ownership, surface and subsurface rights, and control of access

1.2.2 Types of Findings Specified in the Siting Guidelines

Appendix III of the DOE Siting Guidelines specifies how the guidelines are to be used at a particular stage of the siting process. Levels of findings are defined depending on the likelihood that new information could change the conclusion about the suitability of the site. Level 1 and Level 2 findings are used with disqualifying conditions, while Level 3 and Level 4 findings are used with qualifying conditions. Levels 1 and 3, however, are commonly referred to as lower-level suitability findings, and denote a "lower level" of confidence in the conclusion. Levels 2 and 4 are commonly called higher-level suitability findings and indicate that there is a "higher level" of confidence that new information will not change the conclusion. Each

Table 1-2. Preclosure Guideline Descriptions From the U.S. Department of Energy (DOE) Siting Guidelines in 10 CFR Part 960.

Guideline	Condition	Description
	PRECLOSURE RADIOLOGICAL SAFETY	
System Guideline	Qualifying	Preclosure exposures meet applicable safety standards
Technical Guidelines		
Population Density and Distribution	Qualifying	1. Doses to highly populated areas are not likely to exceed small fraction of limits
		2. Dose to any member of public in unrestricted area is not likely to exceed limits
	Disqualifying	1. Site located in a highly populated area
		2. Site located adjacent to a one-square-mile area with population greater than 1,000
		3. DOE cannot develop emergency preparedness program
Site Ownership and Control	Qualifying	DOE can obtain ownership, surface and subsurface rights, and control of access
Meteorology	Qualifying	Meteorological conditions are not likely to lead to releases above limits
Offsite Installations and Operations	Qualifying	Effects from offsite facilities can be accommodated and will not lead to releases above limits
	Disqualifying	Irreconcilable conflicts with atomic energy defense activities are expected

Table 1-2. Preclosure Guideline Descriptions From the U.S. Department of Energy (DOE) Siting Guidelines in 10 CFR Part 960. (continued)

Guideline	Condition	Description
ENVIRONMENTAL QUALITY - SOCIOECONOMIC IMPACTS - TRANSPORTATION		
System Guideline	Qualifying	Public and environment are adequately protected
Technical Guidelines		
Environmental Quality	Qualifying	Environmental quality is adequately protected
	Disqualifying	1. Environment cannot be adequately protected or impacts acceptably mitigated
		2. Site is located within protected area
		3. Irreconcilable conflicts are expected with a protected area
Socioeconomic Impacts	Qualifying	Impacts can be offset by reasonable mitigation or compensation
	Disqualifying	Significant reduction in water quality/quantity at offsite sources is expected
Transportation	Qualifying	1. Access routes will not cause irreconcilable conflicts with a protected area
		2. Routes can be designed with reasonably available technology
		3. No extreme performance standards are required
		4. No unacceptable risks or environmental impacts are expected

Table 1-2. Preclosure Guideline Descriptions From the U.S. Department of Energy (DOE) Siting Guidelines in 10 CFR Part 960. (continued)

Guideline	Condition	Description
EASE AND COST OF SITING, CONSTRUCTION, OPERATION, AND CLOSURE		
System Guideline	Qualifying	Repository siting, construction, operation, and closure will be feasible using reasonably available technology
Technical Guidelines		
Surface Characteristics	Qualifying	Can be accommodated using reasonably available technology
Rock Characteristics	Qualifying	1. Thickness and lateral extent are adequate 2. No undue hazards to personnel are expected 3. Reasonably available technology will be adequate
	Disqualifying	Presence of significant risk to health and safety of personnel taking into account possible mitigation using reasonably available technology
Hydrology	Qualifying	1. Setting is compatible with repository development 2. Liners and seals will function as designed 3. Reasonably available technology will be adequate
	Disqualifying	Expected ground-water conditions require engineering measures beyond reasonably available technology

Table 1-2. Preclosure Guideline Descriptions From the U.S. Department of Energy (DOE) Siting Guidelines in 10 CFR Part 960. (continued)

Guideline	Condition	Description
Tectonics	Qualifying	Expected tectonic activity can be accommodated with reasonably available technology
	Disqualifying	Expected fault movement will require engineering measures beyond reasonably available technology

level is further subdivided into parts (a) and (b). Part (a) of each level specifies conditions for a suitability finding. Part (b) specifies conditions for an unsuitability finding.

Formal statements of these findings are given in Appendix III of the guidelines. Table 1-3 summarizes the findings, which are further discussed in the following paragraphs. Both the numbered levels and the terms "lower-level" and "higher-level" are used throughout the rest of this report.

Unsuitability Finding. If the evidence supports a conclusion that a disqualifying condition is present or is likely to be present or that a qualifying condition cannot be met or is unlikely to be met, then the result is an unsuitability finding. If DOE were to make a formal unsuitability finding, the site should be recommended for disqualification.

Lower-level Suitability Finding (Levels 1 and 3). A lower-level suitability finding is the negation of an unsuitability finding. A lower-level finding can be supported when current information does not indicate that the site is unsuitable. There is, however, a possibility that additional information could change the conclusion, and thus, that the site could still be found unsuitable.

Higher-level Suitability Finding (Levels 2 and 4). A higher-level suitability finding can be supported when it is judged unlikely that future information could change the conclusion. This finding would occur when there is high confidence in the conclusion drawn from available information.

A higher-level finding does not necessarily mean that remaining uncertainties concerning the site's ability to satisfy a guideline have been resolved. Rather, the higher-level finding means that resolving any remaining uncertainties is unlikely to change the current conclusion about the suitability of the site.

Table 1-3. Definitions of Findings Specified by DOE's Siting Guidelines

Conclusion	Suitability Finding	Suitability Level[a]
DISQUALIFYING CONDITIONS		
Condition is present or likely to be present	Unsuitability	1(b) or 2(b)
Condition is not present but additional information could change conclusion	Lower-level suitability	1(a)
Condition is not present and it is unlikely that the conclusion will change with additional information	Higher-level suitability	2(a)
QUALIFYING CONDITIONS		
Site cannot meet the condition or is not likely to meet the condition	Unsuitability	3(b) or 4(b)
Site is likely to meet the condition but additional information could change the conclusion	Lower-level suitability	3(a)
Site meets the condition and it is unlikely that the conclusion will change with additional information	Higher-level suitability	4(a)

[a]As defined in Appendix III, 10 CFR Part 960

There may be several reasons for continued site characterization or for conducting other activities after higher-level suitability findings are believed to be supported. For example, even though the results of site characterization activities are not expected to change conclusions about site suitability, those activities may be critical to complete or to improve repository designs. Similarly, the activities may be needed to support studies in other areas where there is less confidence in site suitability conclusions. For example, it may be determined that there is sufficient understanding of ground-water chemistry conditions to support a higher-level finding on the Geochemistry Guideline. However, additional information on ground-water chemistry might be necessary to develop a better understanding of the ground-water system and, therefore, to judge suitability with respect to the Geohydrology Guideline.

The licensing process also provides additional motivations for conducting activities that go beyond site suitability concerns. There also may be specific requirements for testing (or monitoring) to prepare an Environmental Impact Statement. In addition, even if there is high confidence that additional information will not change conclusions about site suitability, the DOE may determine that it is prudent to continue activities to address residual uncertainties, to build confidence in models, to confirm performance estimates, or to provide additional assurance to review boards or other parties in the siting and licensing processes.

1.2.3 Findings from the Environmental Assessment

The EA concluded that the Yucca Mountain site was suitable for site characterization, based on information that was available at that time (DOE, 1986). Lower-level suitability findings were made on all of the qualifying and disqualifying conditions, except that higher-level suitability findings were made for the qualifying and disqualifying conditions associated with the Dissolution Guideline and two of three disqualifying conditions for the Population Density and Distribution Guideline. The EA reported no unsuitability findings.

The evaluations that led to the EA findings were made by considering the favorable and potentially adverse conditions that are associated with each of the technical guidelines. These are generic conditions that are provided in the Siting Guidelines for use as early indicators of site acceptability, before detailed studies of the site are performed. The EA findings were reached by considering, on balance, the presence or absence of the favorable and potentially adverse conditions related to each guideline.

1.2.4 Sequence of Steps in the Early Site Suitability Evaluation

This early site suitability evaluation determined the level of findings that can be supported by current information about the site. Figure 1-3 illustrates the decision logic used to make that determination for the disqualifying and qualifying conditions associated with each siting guideline.

Evaluation of Disqualifying Conditions. Disqualifying conditions were evaluated by examining specific features or conditions at the site that could make it unsuitable for the development of a repository. For example, one disqualifying condition (associated with the Postclosure Human Interference Technical Guideline) is the occurrence of previous mining at the site that could adversely affect future repository-system performance. Thus, the evidence for and potential consequences of previous mining at the site was analyzed.

The evaluation of a particular disqualifying condition consists of two steps. First, the site information is evaluated to determine if the disqualifying condition is present or likely to be present at the site. This evaluation begins by interpreting the condition in terms of specific features and conditions at the site. For example, the concept of ground-water travel time must be interpreted in terms of the unsaturated-zone and saturated-zone

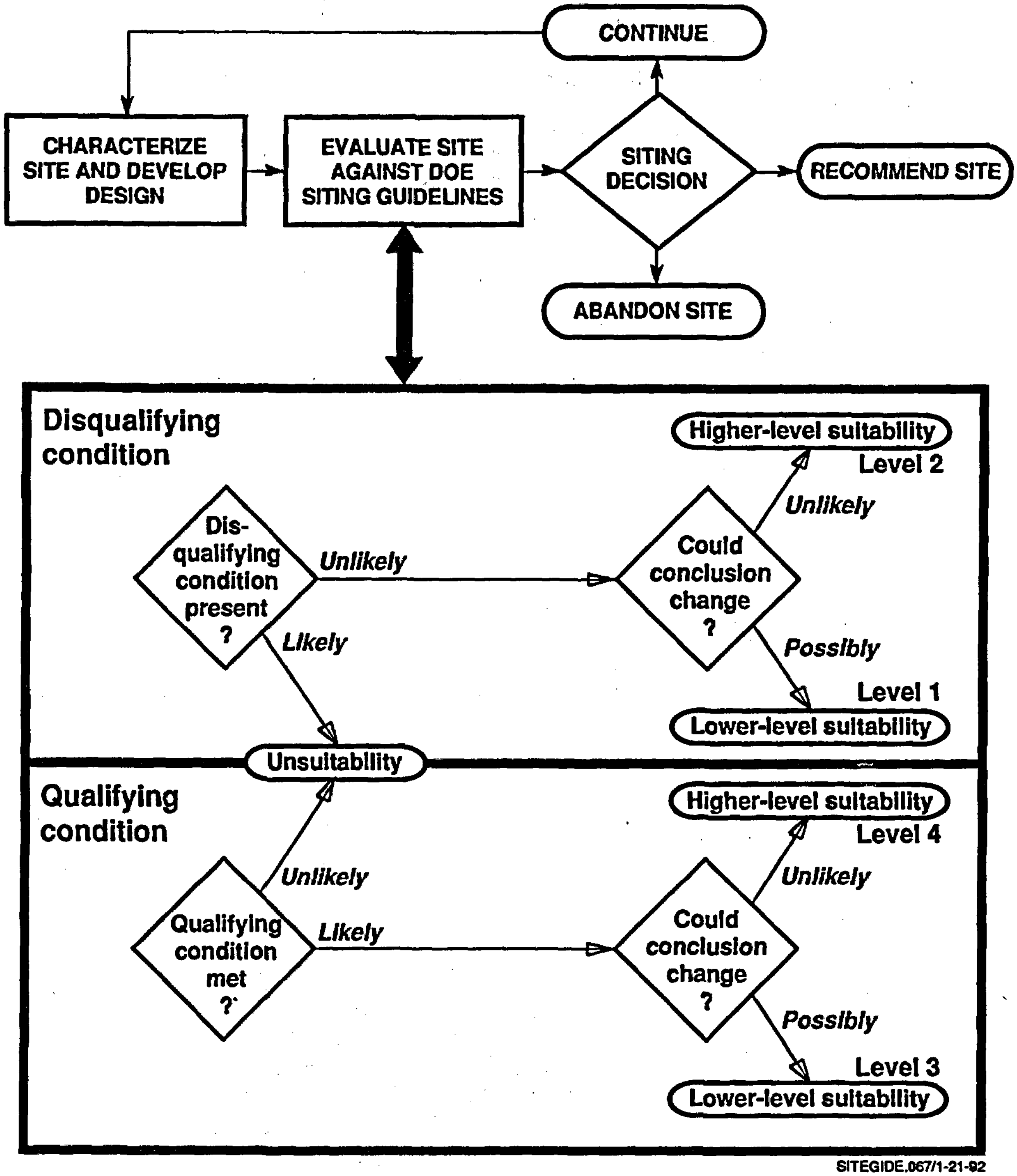


Figure 1-3. Decision logic for suitability and unsuitability findings, based on DOE Siting Guidelines. The primary distinction between lower- and higher-level suitability findings is the likelihood that further information will change conclusions about the suitability of the site for repository development. A higher-level suitability finding is supported when it is unlikely that additional data will change current conclusions; a lower-level suitability finding is supported when additional information could possibly change current conclusions.

geohydrology at the Yucca Mountain site before the ground-water travel time disqualifying condition can be evaluated. If the condition is determined to be present or likely to be present, an unsuitability finding would be supported; otherwise, a lower-level (Level 1) suitability finding would be supported.

Second, the site information is evaluated to determine if a higher-level (Level 2) suitability finding can be supported. This analysis examines uncertainties in site information and issues important to determining whether the condition is present. If no significant issues can be identified and, therefore, additional information is unlikely to show the site is unsuitable, then a higher-level suitability finding can be supported. Otherwise, only a lower-level suitability finding can be supported.

Evaluation of Qualifying Conditions. The qualifying conditions for each technical guideline specify requirements for conditions and features that must be present at the site in order for the Postclosure and Preclosure System Guideline to be met. The evaluation of a qualifying condition, therefore, begins by assessing the system and available site data and evidence to determine if the requirements specified in the condition can be met. First, variables, which can be used to judge compliance with the requirements, are identified. For example, for the postclosure qualifying conditions, these variables are the performance measures identified in the Postclosure System Guideline. For the Preclosure Radiological Safety Guidelines, these variables are the measures of preclosure radiological exposure identified in the criteria referenced in the System Guideline. For the Environmental Quality, Socioeconomic Impacts, and Transportation Guidelines, the variables are related to the potential impacts and mitigation measures needed to avoid unacceptable impacts. For the Ease and Cost of Siting, Construction, Operation, and Closure Guidelines, these variables are related to the availability of technology needed to site, construct, operate, and close the repository.

Next, site information associated with the guideline (e.g., the hydrology or rock characteristics) is evaluated to determine if there are features or conditions that could affect any of the variables identified above. If so, estimates are made to determine if the effects could be large enough to prevent meeting the qualifying condition. Such estimates take into account the uncertainties in current information. If it is unlikely that the condition is met, then the site is unsuitable. If evidence does not support a conclusion that the condition is not met, then a lower-level suitability finding can be supported. If, in addition, further information is unlikely to change the current conclusion about the suitability of the site, then a higher-level finding can be supported. Otherwise, only a lower-level suitability finding can be supported.

In most cases, the qualifying conditions for the technical guidelines must be evaluated with explicit reference to the associated system guideline. This is because qualifying conditions require the presence of site characteristics that will allow the system guideline to be met. Several different sets of related conclusions are then possible:

- If a qualifying condition for a technical guideline is unlikely to be met, then an unsuitability finding is implied for both the technical guideline and the system guideline.

- If a lower-level suitability finding can be supported for the system guideline, then a lower-level suitability finding could be supported for all associated technical guidelines.

- If a higher-level suitability finding can be supported for the system guideline, then higher-level suitability findings could be supported for all associated technical guidelines.

- If higher-level findings can be supported on some, but not all, of the technical guidelines, then only a lower-level finding could be supported on the system guideline.

The circumstances that can lead to the last set of conclusions listed above warrant further discussion. As a hypothetical case, consider a potential repository site for which presently available evidence supports lower-level suitability findings for the Postclosure System Guideline and all of the Postclosure Technical Guidelines. One of these technical guidelines is the Climatic Changes Guideline, which states:

> "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 [the Postclosure System Guideline]. 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 climate conditions in the geologic setting."

Although present information (in this hypothetical example) supports a lower-level finding for the Climatic Changes Guideline, there remains uncertainty concerning the effects of future climatic change on repository system performance, and a question remains about what new information might show. Conceptually, a sensitivity analysis could be conducted to answer this question, using a total system performance model or another evaluation approach. The sensitivity analysis would answer the question, "Are any climatic conditions likely to occur that could cause the system to fail to satisfy the required performance criteria?"

In performing this sensitivity analysis, climatic conditions would be varied over the range of possible conditions from those detrimental to waste containment and isolation to those conditions that are favorable. (For a sensitivity analysis to be valid, however, only one variable--in this instance, climatic conditions--should be varied at a time unless other variables depend on this variable for their values.)

There are two possible conclusions from such a sensitivity study. If the Postclosure System Guideline is met for all likely climatic conditions, this means that new information about climate is unlikely to change the conclusion about site suitability with regard to future climate. Therefore, a higher-level suitability finding could be supported for the Climatic Change qualifying condition, even though only a lower-level finding would be possible for the System Guideline. If, on the other hand, some of the climatic conditions cause the System Guideline to be violated and if these are deemed "possible but not likely," then only a lower-level suitability finding can be supported. A sensitivity analysis approach can be applied to all of the technical guidelines.

In conducting this early site suitability evaluation, no single total system performance model was used to evaluate postclosure performance. However, results of several different models were considered when answering questions about the likelihood that new information could change conclusions. Further, the Core Team adopted this "sensitivity analysis" approach as a conceptual framework for judging whether higher-level suitability findings could be supported for the qualifying conditions of all the technical guidelines.

Critical to any of these analyses of whether higher-level suitability findings can be supported is a judgment about what constitutes a "likely" or "unlikely" event. The Core Team generally interpreted "likely" in the quantitative sense of probability or likelihood. In conducting their evaluations, the team members, therefore, estimated the likelihood that a condition would be present at the site and, additionally, the likelihood necessary to support the suitability findings specified by 10 CFR Part 960. In making such judgments, the team members also factored in their opinion on the relative importance of the particular condition in relation to site performance. Thus, each judgment of the team members considered the nature of the condition, the likelihood of its being present, and the confidence required in order to reach a suitability finding. The individual judgments were then consolidated into a Core Team consensus position, as will be explained in the next section.

1.2.5 Core Team and Consensus Findings

This early site suitability evaluation was conducted by a Core Team consisting of personnel with expertise in each of the technical areas covered by the Siting Guidelines. The Team, listed in Table 1-4, included representatives from Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Sandia National Laboratories, Science Applications International Corporation (SAIC), the U.S. Geological Survey, Decision Analysis Company, Strategic Insights, and the Weston Technical Support Team. The effort was lead by SAIC, Technical & Management Support Services (T&MSS) contractor for DOE's Yucca Mountain Site Characterization Project Office, under a plan approved by the Office of Geologic Disposal, a unit within the DOE Office of Civilian Radioactive Waste Management.

The Core Team developed an approach for evaluating the suitability of the Yucca Mountain site consisting of the following sequence of actions:

1. Principal responsibility for each siting guideline was assigned to a team member.

2. Available information pertinent to each guideline was reviewed.

Table 1-4. Core Team for Early Site Suitability Evaluation

Name	Organization	Guideline Evaluation/ Area of Expertise
	VOTING CORE TEAM MEMBERS	
Jean L. Younker	Technical & Management Support Services (T&MSS)	Team Lead
Lynden B. Ballou; Michael A. Revelli	Lawrence Livermore National Laboratory	Postclosure Rock Characteristics
William W. Dudley	U.S. Geological Survey	Postclosure Tectonics, Erosion, Surface Characteristics
Dwight T. Hoxie	U.S. Geological Survey	Climatic Changes
Richard J. Herbst; Edward A. Patera	Los Alamos National Laboratory	Geochemistry, Dissolution, Preclosure Rock Characteristics
Larry D. Rickertsen	Weston Technical Support Team	Postclosure System, Ease and Cost System Guideline
Janet A. Docka	Weston Technical Support Team	Rock Characteristics, Geochemistry
Arthur R. DuCharme	Sandia National Laboratories	Preclosure Hydrology, Preclosure Tectonics
Les E. Shephard	Sandia National Laboratories	Postclosure Geohydrology
Steven R. Mattson	T&MSS	Natural Resources
William B. Andrews	T&MSS	Transportation, Offsite Installations & Operations
Gregory A. Fasano	T&MSS	Preclosure Radiological Safety, Environmental Quality, Socioeconomic Impacts, Population Density, Meteorology, Site Ownership & Control
C. Charles Herrington	T&MSS	Licensing

Table 1-4. Core Team for Early Site Suitability Evaluation (continued)

Name	Organization	Guideline Evaluation/ Area of Expertise
	VOTING CORE TEAM MEMBERS (continued)	
Robert C. Murray	T&MSS	General Geology/Deputy Team Lead
	OTHER NONVOTING PARTICIPANTS AND OBSERVERS	
Bruce R. Judd	Decision Analysis Company	Decision Analysis
John F. Lathrop	Strategic Insights	Decision Analysis
K. Michael Cline	Woodward-Clyde Federal Services	Tectonics
Jeremy M. Boak; Jane R. Stockey	Office of Geologic Disposal	U.S. Department of Energy

3. A preliminary position on each guideline was formulated.

4. A small group from the Core Team reviewed the preliminary position.

5. The position and evidence was presented to the entire Core Team for evaluation.

6. On the basis of their evaluation, the Core Team developed a consensus position on each guideline.

Table 1-4 identifies the Core Team members, their affiliations, and the assigned primary responsibilities for each guideline. These members were assisted in their evaluations by other qualified individuals both from the Core Team and from the participating organizations.

In performing the evaluations, the intent was to review all current, relevant information, including that considered in the EA evaluation, as well as new information available since the EA. This information included published and draft reports, abstracts prepared for professional meetings, oral presentations, internal memoranda, and written communications from workers both within and external to the Yucca Mountain Site Characterization Project. The extent of technical review that these materials had previously received was an important consideration by team members.

Based on the available information, the responsible Core Team member developed a position regarding the suitability of the Yucca Mountain site with respect to the Technical and System Guidelines. In developing these positions, the team members considered the type of information available and the applicability of available empirical data to represent site features and conditions and analyses of expected future repository performance under these conditions. Also considered were the various conclusions that could be drawn from the information and analyses.

A small group from the Core Team reviewed each of the preliminary positions for consistency of approach, validity and completeness of information considered, and appropriateness of conclusions.

The development of the consensus position by the Core Team followed and sometimes involved extensive deliberation. The result is that each conclusion presented in this report is a consensus opinion, which was supported by every member of the Core Team. This requirement for consensus sometimes meant that a conclusion to support a lower-level suitability finding resulted because, although all team members might agree that a particular qualifying condition is likely to be met at the site, at least one team member felt that additional information could change the conclusion. In particular, unanimity among the Core Team members was required in order to reach a conclusion to support higher-level suitability findings.

In some cases, the evidence for a particular conclusion was considered to be sufficiently well-founded that unanimous agreement was obtained with little discussion. In other cases where there were many issues, agreement was reached only after extensive discussion concerning the available information and careful evaluation of the bases for judgments by the individual team members. Individual differences regarding the finding were then resolved through a process of discussion and balloting. Of course, not all Core Team members had expert knowledge of every guideline, and in such cases, team members abstained from the balloting. However, all team members agreed that the positions reached through the balloting process represented the consensus of the team.

1.2.6 Review of this Report on the Early Site Suitability Evaluation

In order to ensure the technical soundness and logical consistency of the conclusions presented in this report, it has been subjected to two formal reviews by qualified experts who were not part of the Core Team. The first was conducted by technical experts within the DOE program, in accordance with the T&MSS procedure for technical reviews. Table 1-5 lists these internal reviewers, their affiliation, and their areas of expertise.

A second formal peer review was conducted by a panel of experts who were external to the DOE and the geologic repository program. The primary consideration in selecting these peer reviewers was their technical qualifications in their respective review area. (Qualifications had to be at least equivalent to those needed to conduct the evaluation.) The selected peer reviewers were either university faculty members or private consultants. The peer review team, their affiliations, and their areas of expertise are provided in Table 1-6.

Table 1-5. Reviewers for Early Site Suitability Evaluation from within the DOE Program

Name	Organization	Review Responsibilities
Henry Shaw	Lawrence Livermore National Laboratory	Geochemistry, Rock Characteristics
John Whitney	U.S. Geological Survey	Tectonics, Erosion, Rock Characteristics
Dan Gillies	U.S. Geological Survey	Geohydrology, Preclosure Hydrology, Climatic Change
Alan Flint	U.S. Geological Survey	Meteorology
Bruce Crowe	Los Alamos National Laboratory (LANL)	Tectonics
Julie Canepa	LANL	Geochemistry, Rock Characteristics
Scott Sinnock	Sandia National Laboratories (SNL)	Postclosure System Guideline, Tectonics
Felton Bingham	SNL	Postclosure System Guideline, General Overview
K. Michael Cline	Woodward-Clyde Federal Services	Tectonics, General Geology
Robert Gamble	Weston Technical Associates	General Overview
Douglas Chandler	Technical & Management Support Services (T&MSS)	General Overview
Gary Daer	T&MSS	Population Density (Emergency Response)
James Harper	T&MSS	Quality Assurance
Robert Kimble	T&MSS	Socioeconomic Impacts
Larry LaMonica	T&MSS	Offsite Installations
Edward McCann	T&MSS	Environmental Quality
Dennis Sorenson	T&MSS	Radiological Safety

Table 1-6. External Peer Reviewers for Early Site Suitability Evaluation

Name	Organization	Area of Expertise
Stan L. Albrecht	Brigham Young University Provo, UT	Socioeconomic Impacts
Walter J. Arabasz	University of Utah Salt Lake City, UT	Preclosure Tectonics
John H. Bell	University of Nevada, Las Vegas Las Vegas, NV	Health Physics & Radiological Safety
F. William Cambray	Michigan State University East Lansing, MI	Structural Geology, Tectonics
Steven W. Carothers	SWCA, Inc. Environmental Consultants Flagstaff, AZ	Environmental Quality
James Drever	University of Wyoming Laramie, WY	Geochemistry
Marco T. Einaudi	Stanford University Stanford, CA	Economic Geology
Don E. French	Petroleum Geologist Billings, MT	Petroleum Geology
Kip V. Hodges	Massachusetts Institute of Technology Cambridge, MA	Tectonics-General
Robert J. Jones	Hazardous Material Systems, Inc. Los Gatos, CA	Transportation Impacts
David K. Kreamer	University of Nevada, Las Vegas Las Vegas, NV	Hydrology
William G. Pariseau	University of Utah Salt Lake City, UT	Rock Characteristics, Engineering Geology

Table 1-6. External Peer Reviewers for Early Site Suitability Evaluation (continued)

Name	Organization	Area of Expertise
Thomas A. Vogel	Michigan State University East Lansing, MI	Tectonics-Volcanology
Thompson Webb, III	Brown University Providence, RI	Climatic Change

Peer reviewers were asked (a) to evaluate the completeness and adequacy of information presented in support of conclusions in the report and (b) to determine if the report represented an objective and technically defensible evaluation of the suitability of the Yucca Mountain site. Individual peer reviewers were asked to focus their reviews on their respective area(s) of expertise, on a guideline-by-guideline basis.

1.3 DESCRIPTION OF THE YUCCA MOUNTAIN SITE AND POTENTIAL REPOSITORY SYSTEM

The Yucca Mountain site and the repository system that might be developed at that site are briefly discussed below. This description is drawn from the Overview to the Site Characterization Plan (DOE, 1988a) and is intended to provide a general orientation for the reader, based upon the current understanding of the site. Additional details about characteristics of the site and the repository system are discussed along with the specific technical and system guidelines in Sections 2 and 3.

1.3.1 The Yucca Mountain Site

The Yucca Mountain site is in Nye County, southern Nevada, about 160 km by road northwest of Las Vegas (Figure 1-4). As shown in Figure 1-4, the site is located on federal lands consisting of public lands managed by the Bureau of Land Management of the Department of the Interior, the Nellis Air Force Range, and the DOE's Nevada Test Site.

The site lies in the southern part of the Great Basin, which is a semiarid region characterized by linear mountain ranges and intervening valleys, sparse vegetation, and little population. Yucca Mountain consists of a group of north-trending ridges that extend southward from Beatty Wash on the northwest to U.S. Highway 95 in the Amargosa Desert (Figure 1-5). The highest point of Yucca Mountain is about 1,500 m above sea level, more than 400 m above the western edge of Jackass Flats to the east, and more than 300 m above the eastern edge of Crater Flat to the west.

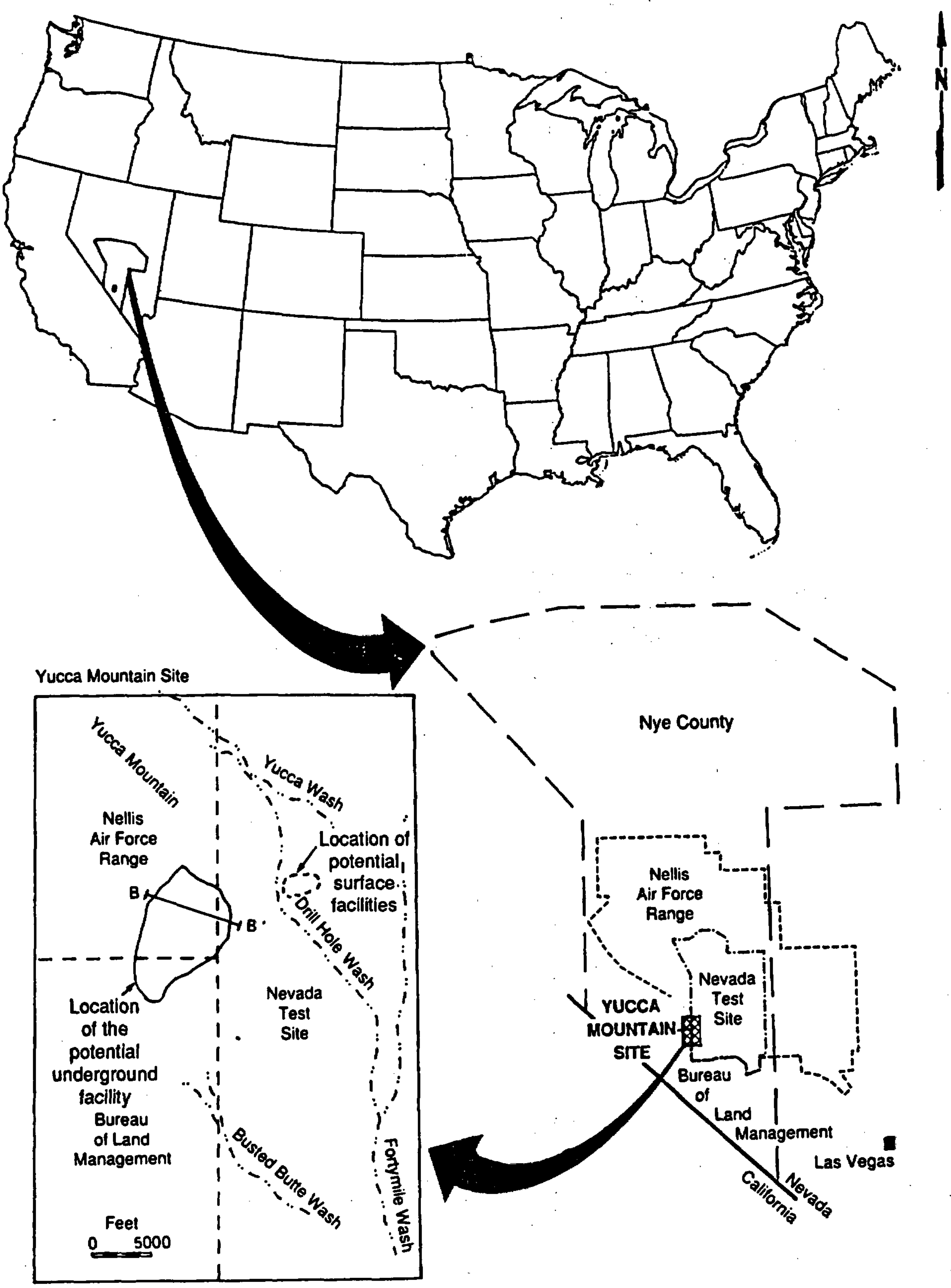


Figure 1-4. Location of the Yucca Mountain site in southern Nevada. The line labeled B-B' marks the location of the cross section shown in Figure 1-6.

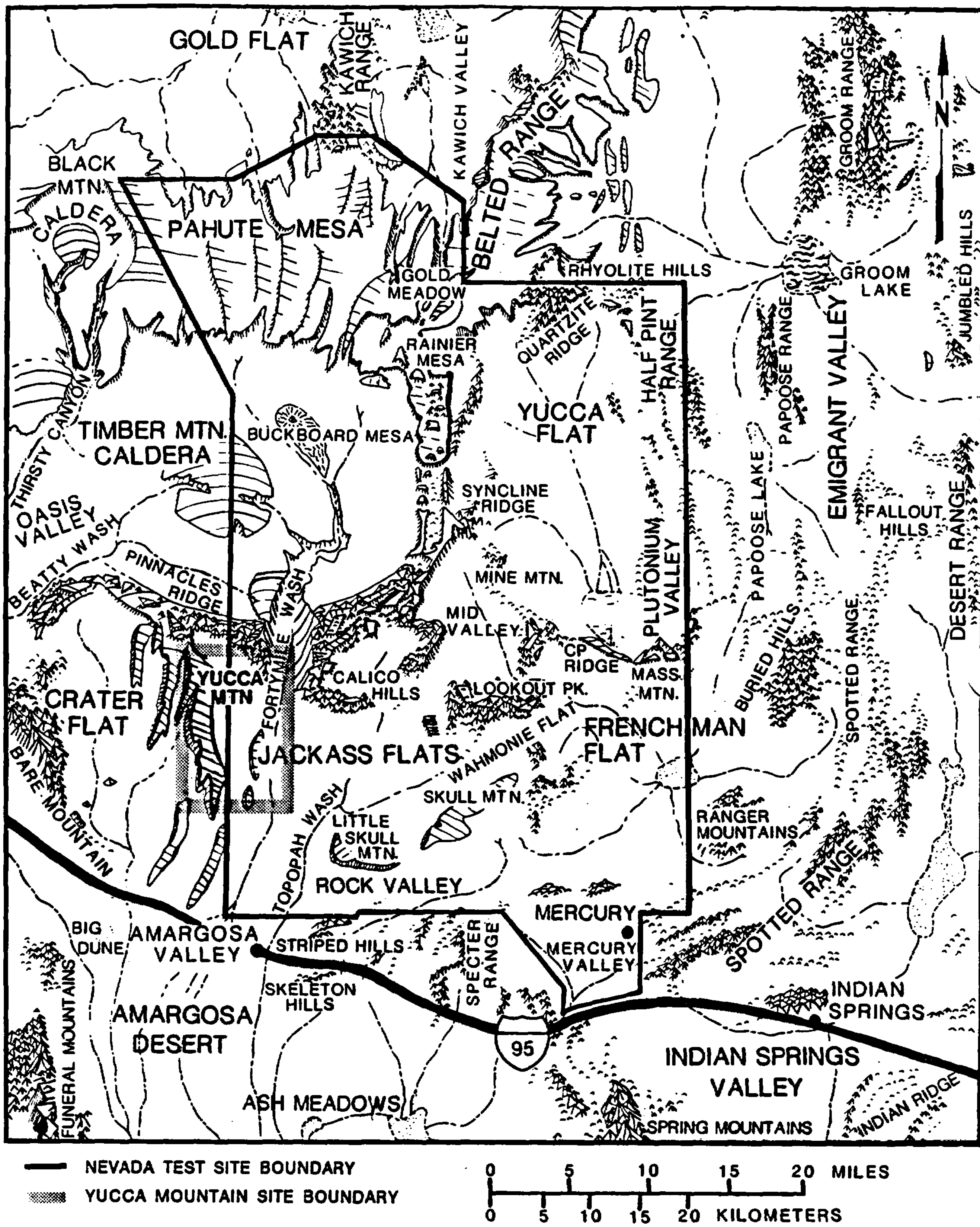


Figure 1-5. Physiographic features of Yucca Mountain and the surrounding region.

Yucca Mountain is underlain by a layered sequence of silicic volcanic rocks that range in thickness from 1,000 m to more than 3,000 m and dip 5 to 10 degrees to the east at the location of the potential repository (Figure 1-6). These rocks consist mainly of welded and nonwelded ash-flow and air-fall tuffs. The candidate horizon for the potential repository is in an ash-flow unit, the Topopah Spring Member of the Paintbrush Tuff Formation. Of the four members of the Paintbrush Tuff, the Topopah Spring Member is the lowermost, thickest, and most extensive in the Yucca Mountain area. At Yucca Mountain, this unit varies in thickness but averages about 330 m thick.

The Timber Mountain-Oasis Valley caldera complex, to the north of the potential repository site, erupted these ash-flow tuffs, between 16 and 9.5 million years ago (mya), with deposition of the Paintbrush tuff occurring about 13 mya. While silicic volcanism has ceased in the area, there is evidence of more recent basaltic volcanism, and cinder cones less than 2 million years old are present in the area. Several episodes of basaltic volcanism occurred since the late Miocene, and some activity may be younger than 140,000 years. North-trending extensional faulting in the area started at about the same time as the silicic volcanism, between 16 to 14 mya, with most of the offset in the vicinity of the site occurring between 12.9 and 11.6 mya (DOE, 1988a), after deposition of the Paintbrush tuff. Continued extensional faulting, associated with development of the Basin-and-Range Province during the last 7 million years, dominates the modern topography at the site.

Yucca Mountain is composed of a series of north-trending structural blocks that have been tilted eastward along west-dipping, high-angle normal faults. The underground facility for the potential repository would be located in one of these structural blocks. This block is bounded on the west by the Solitario Canyon fault, on the northeast by an inferred fault in Drill Hole Wash, and on the east and southeast by an hypothesized series of imbricate normal faults. One of the north-trending faults, the Ghost Dance fault, transects the potential repository layout within this block.

The Yucca Mountain site is about 160 km to the east of the Nevada-California seismic belt and about 240 km to the southwest of the Intermountain seismic belt. The site is also on the southern margin of the Nevada East-West seismic belt (DOE, 1988a). During the time for which records are available, eight major earthquakes (with magnitudes of 6.5 or greater) have occurred within about 400 km of Yucca Mountain. However, the area immediately surrounding Yucca Mountain (including the eastern Mojave Desert and the southwest quadrant of the Nevada Test Site) has been relatively quiet seismically since the 1850s, when the historical earthquake record for the region began.

No perennial streams occur near the Yucca Mountain site. The only reliable sources of surface water in the area are the springs in Oasis Valley, the Amargosa Desert, and Death Valley. Because of the aridity of the region, most of the water discharged by these springs travels only a short distance before evaporating or infiltrating into the soil; therefore, these springs do not provide sources of surface water near the site. However, during intense storms, transient flooding may occur in the arroyos near the site.

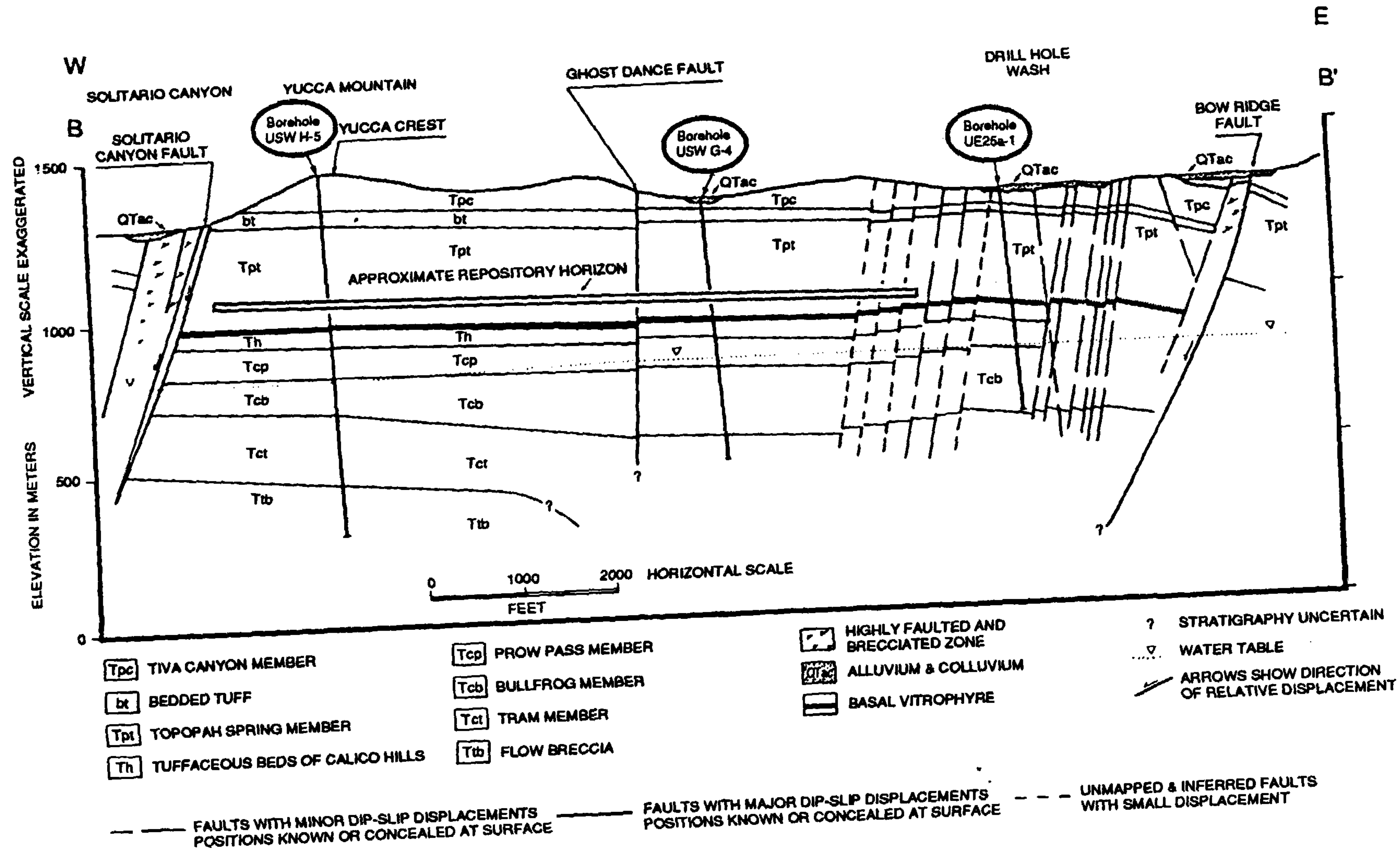


Figure 1-6. East-west geologic cross section for the Yucca Mountain site (see Figure 1-4 for the location of B-B'). This figure shows the relative positions of various rock units at the site, including the unit proposed for the potential repository and the fault zones that are closest to the site.

The potential repository horizon is in the unsaturated zone at a depth of more than 200 m below the surface and at least 250 m above the water table. Current estimates indicate that only a small amount of the precipitation that falls on Yucca Mountain infiltrates into the deep unsaturated zone, and only a small vertical ground-water flux is expected to be moving downward through the Topopah Spring Member in which the underground facility would be constructed.

Water that percolates through the unsaturated zone to the water table will enter the tuff aquifer, as part of a regional ground-water subbasin. The subbasin discharges through the Franklin Lake Playa at Alkali Flat in California and possibly at springs in Death Valley near Furnace Creek Ranch.

1.3.2 The Potential Repository System

A geologic repository system includes the site, surface facilities, underground facility, ramps and shafts connecting the underground and surface facilities, and waste packages that will be placed in the underground facility. In addition, there may be other engineered barriers placed within the underground facilities, and there will be seals constructed for the shafts and ramps. A sketch of the Exploratory Studies Facility (ESF) and the repository facilities proposed for the Yucca Mountain site is shown in Figure 1-7. These designs are preliminary and conceptual and may well be subjected to significant changes during advanced design phases.

Surface Facilities. The current plan is to build surface facilities east of Yucca Mountain, on ground that is relatively flat. They would consist of central surface facilities, various outlying support facilities, and facilities that would provide access and ventilation for the underground facility. A rail spur would be constructed for the waste that is shipped by rail. The central surface facilities include waste-handling buildings where the radioactive waste would be received and readied for emplacement in the underground facility.

Ramps and Shafts. The surface facilities would be connected to the underground facility through ramps and shafts as shown in Figure 1-7. For example, a ramp would be used to transport the waste packages from the surface to the underground waste-emplacement area and to provide a fresh-air intake for operations in the underground facility. Another ramp would be used for construction access and for removal of excavated material. These ramps would have lengths of several kilometers and grades of less than 10 percent, depending on the final layout and design. The current plan also incorporates shafts for men-and-material access and for exhaust of ventilation air from the underground facility.

The ESF will allow in situ testing at depth during site characterization and will be designed to be compatible with the plan for repository shafts and ramps. That is, the openings planned for the ESF will eventually be used in the repository system design. Figure 1-7 shows that current plans include underground exploration in rock units at two depths--the Topopah Spring Member and the underlying Calico Hills unit.

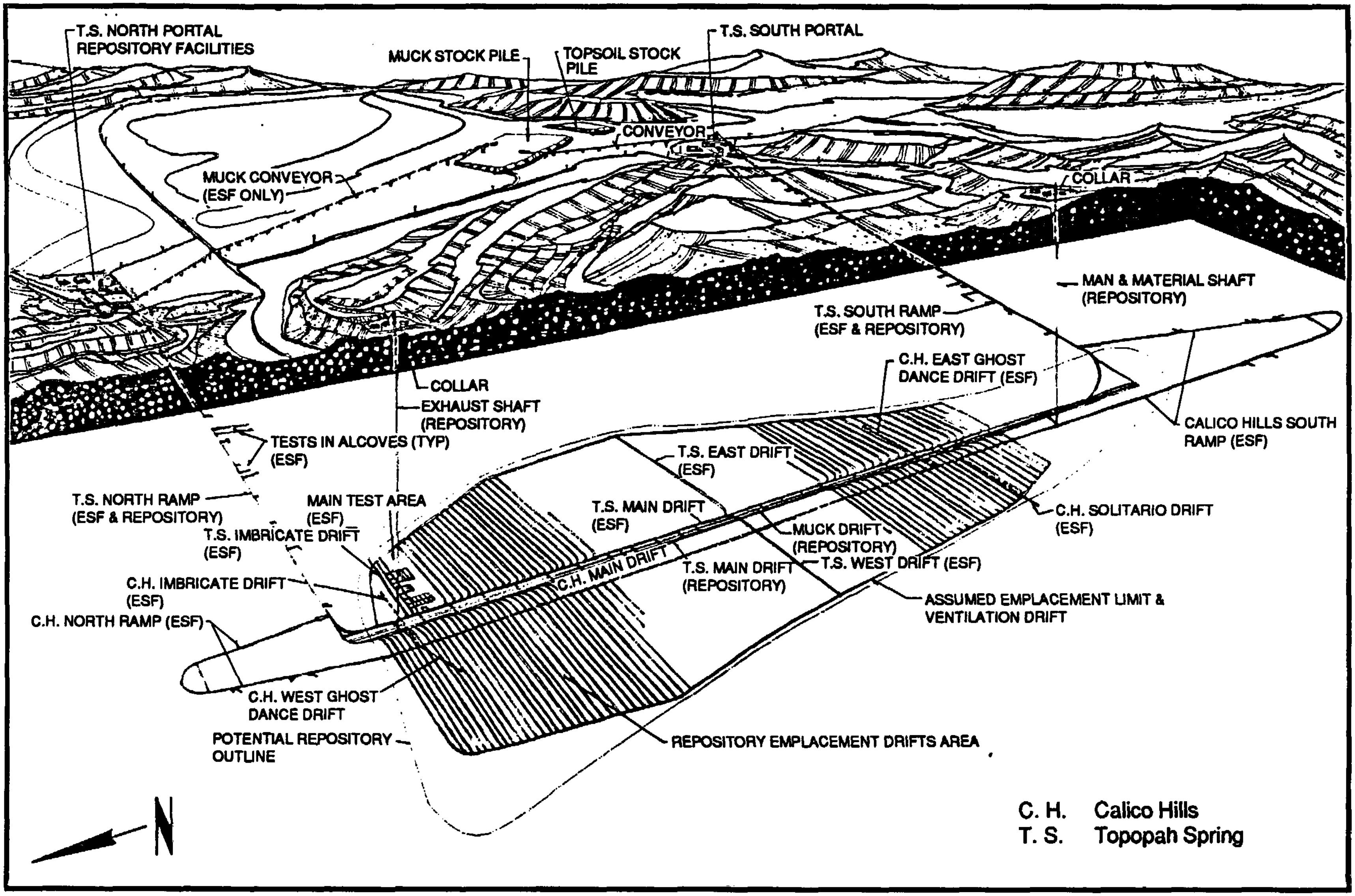


Figure 1-7. Perspective of the Exploratory Studies Facility showing relationship to potential repository facilities.

Underground Facility. The underground facility would be constructed more than 200 m below the eastern flank of Yucca Mountain, in the Topopah Spring Member of the Paintbrush Tuff. This facility is intended to accommodate high-level radioactive waste associated with the equivalent of 70,000 metric tons of heavy metal. The waste includes both spent reactor fuel and reprocessing wastes, including defense high-level wastes.

The facility, as planned, includes main access drifts and waste-emplacement panels as shown in Figure 1-7. Each panel would contain a number of drifts in which the waste packages would be emplaced. Figure 1-8 shows a possible emplacement configuration, in which an emplacement borehole is drilled in the floor of a drift, the waste package is inserted, and the emplacement borehole is backfilled and closed.

Waste Package. The waste package consists of the waste form (e.g., spent-fuel elements or vitrified high-level waste) and a disposal container. The specific design for the waste packages has not yet been selected, but reference designs have been developed. For example, Figure 1-9 shows reference designs for a spent-fuel package and for a defense high-level waste package. The reference spent-fuel package contains about two metric tons of spent fuel, and there would be about 35,000 of these reference waste packages in the reference repository. The container in these reference designs is a metal cylinder of steel, nickel, or copper alloy. The container wall thickness in this reference design is about one centimeter, but thicker walls are being considered.

Because of radioactive decay, the waste will generate radiation and heat within the underground facility. The radiation will be accommodated by the host rock and by shielding placed in and over the emplacement boreholes. Heat generation can be controlled in the repository design by the spacing of the waste packages in the emplacement drifts. The current plan is to space packages so that the average rate of heat generation in the underground facility will not exceed 15 watts per square meter (60 kilowatts per acre), and the temperature in the rock will not exceed 150°C.

Waste Containment and Isolation. Containment is the term used by the NRC to describe confinement of the radioactive waste within the waste package for a period of 300 to 1,000 years. According to the NRC, the containment period is the first several hundred years following permanent closure of a geologic repository, when radiation and thermal levels are high and the uncertainties in assessing repository performance are large. During this time, "special emphasis is placed upon the ability to contain the wastes by waste packages within an engineered barrier system." In 10 CFR Part 960, DOE more generally describes containment as "...confinement of radioactive waste within a designated boundary." In 40 CFR Part 191, the EPA used the term containment to describe its 10,000-year cumulative release requirements.

Isolation is defined in 10 CFR Part 960 as "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." The NRC uses the phrase "isolation of waste" (10 CFR 60.102 (e)) to include both containment by the engineered-barrier system and "isolation of wastes by virtue of the characteristics of the geologic repository." The EPA only uses the term "isolation" to describe "disposal" as "permanent isolation of spent

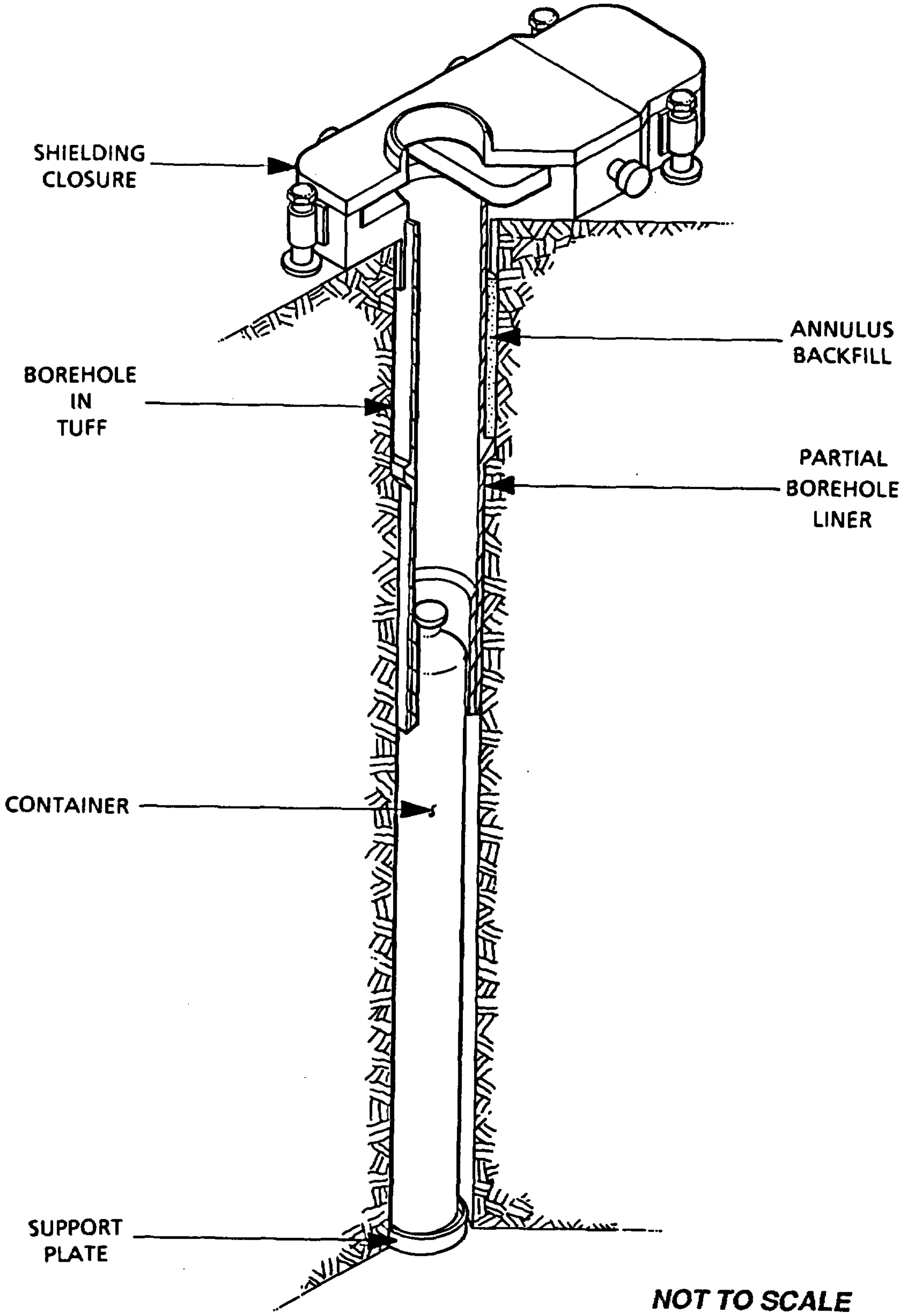


Figure 1-8. Possible configuration for waste emplacement. This configuration shows a vertical waste-emplacement borehole that would be drilled in the floor of the emplacement drifts.

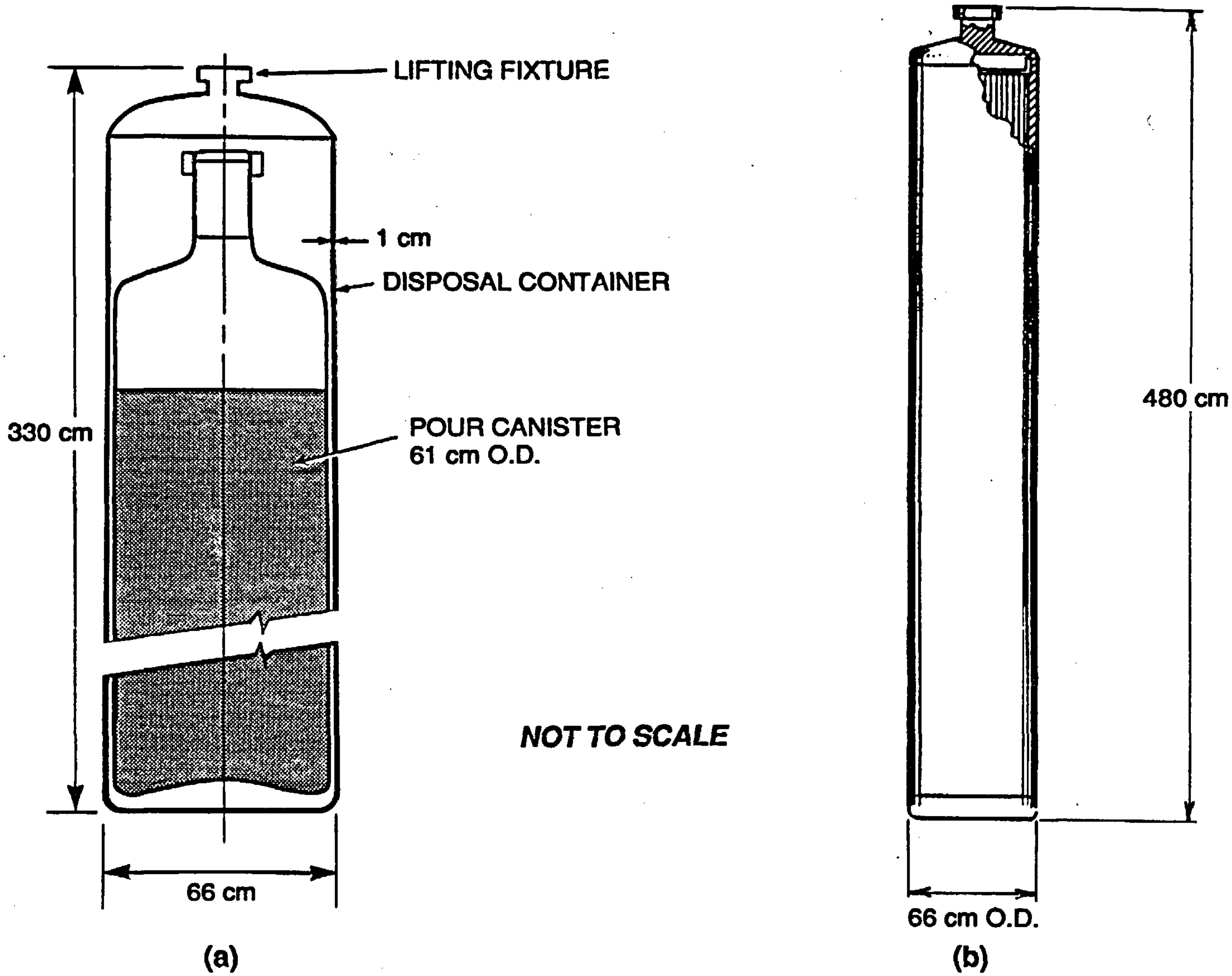


Figure 1-9. Possible waste packages for defense high-level waste (a) and spent-fuel (b).

nuclear fuel or radioactive waste from the accessible environment with no intent of recovery...."

The EPA describes a "barrier" as any material or structure that prevents or substantially delays movement of water or radionuclides toward the accessible environment." The engineered-barrier system is defined in 10 CFR Part 960 as "the manmade components of a disposal system designed to prevent the release of radionuclides from the underground facility or into the geohydrologic setting...." The NRC defines the engineered barrier system as "the waste packages and the underground facility."

1.4 STRUCTURE OF THIS REPORT

The remainder of this report presents the results of this early site suitability evaluation. The evaluations of the Yucca Mountain site against the Siting Guidelines are presented in Section 2 (Postclosure Guidelines) and Section 3 (Preclosure Guidelines). The conclusions of the evaluations are summarized, and recommendations for actions that might be taken by the DOE are presented in Section 4.

The evaluation of each group of guidelines (e.g., postclosure) begins with a discussion of the guideline group and of the general requirements associated with that guideline group identified in the system guideline. Then, the evaluations of the individual technical guidelines are presented. The discussion of these guidelines identifies the issues the Core Team believes should be resolved before making conclusions about the suitability of the Yucca Mountain site. The evaluation of the System Guideline follows. This evaluation considers the issues addressed in the technical guideline evaluations and presents the overall system evaluation relevant to the guideline group.

The types of findings that can be supported by the current information are discussed for the disqualifying and qualifying conditions of each guideline group. Where uncertainties are significant or where issues need to be resolved, an approach to resolving of these issues is discussed.

Report of Early Site Suitability Evaluation of the Potential Repository Site at Yucca Mountain, Nevada

<u>SECTION 2:</u> ***<u>POSTCLOSURE GUIDELINES</u>***

January 1992

2.0 EVALUATION OF THE POSTCLOSURE GUIDELINES

2.1 DESCRIPTION OF THE POSTCLOSURE GUIDELINES

The Postclosure Guidelines are concerned with site characteristics and engineered barriers that affect waste isolation and containment after waste emplacement and repository closure. These considerations relate to long-term protection of public health and safety.

System Guideline: The broad requirements of the Postclosure Guidelines are stated in the Postclosure System Guideline (10 CFR 960.4-1(a)):

> "The geologic setting at the site shall allow for the physical separation of radioactive waste from the accessible environment after closure in accordance with the requirements of 40 CFR Part 191, Subpart B, as implemented by the provisions of 10 CFR Part 60. The geologic setting at the site will allow for the use of engineered barriers to ensure compliance with the requirements of 40 CFR Part 191 and 10 CFR Part 60."

The applicable requirements cited in the guideline are the containment, individual-protection, and ground-water protection requirements of the Environmental Protection Agency (EPA) standards (40 CFR 191.13, 191.15, and 191.16) and the engineered barrier system (EBS) performance objectives in U.S. Nuclear Regulatory Commission (NRC) regulations (10 CFR 60.113). (Subpart B of 40 CFR Part 191, which includes the containment, individual-protection, and ground-water protection requirements, has been remanded to the EPA for reevaluation. If and when the EPA modifies this regulation, the DOE will need to reevaluate its approach to addressing it. For purposes of this report, site evaluations are conducted based on current EPA rules.)

In addition to noting the NRC and EPA requirements that are cited in the System Guideline, the specific requirements not included are also important. For example, the containment requirements of the EPA standards are included only to the degree that they have been implemented by the NRC. In addition, the Postclosure System Guideline does not explicitly cite NRC's ground-water travel-time requirement. Instead, a ground-water travel-time requirement is imposed by the disqualifying condition of the Postclosure Technical Guideline for Geohydrology.

Technical Guidelines: The Postclosure Technical Guidelines identify detailed geologic site characteristics and processes to be considered when evaluating whether the site meets the broad requirements of the System Guideline. These considerations are divided into the technical categories of geohydrology, geochemistry, rock characteristics, climatic changes, erosion, dissolution, tectonics, and human interference (relating to both natural resources and site ownership and control).

These technical guidelines also provide a mechanism for determining whether NRC siting criteria found in 10 CFR 60.122, which will apply during licensing, are likely to be met should the site be found suitable by the DOE. Section II(C) of the Supplementary Information for 10 CFR 960 describes the negotiations between the DOE and NRC that led to NRC concurrence on the guidelines. By fulfilling the requirements of the Postclosure System Guideline and by explicitly considering the Postclosure Technical Guidelines, the DOE will probably gain confidence that the requirements of NRC's siting criteria can be met.

2.2 GENERAL METHOD FOR EVALUATING THE SITE AGAINST THE POSTCLOSURE GUIDELINES

The site is evaluated against the Postclosure System and Technical Guidelines by considering first the technical guidelines, followed by the system guideline. The technical guideline evaluations are conducted with two objectives in mind. The first objective is to determine if there are any specific features or conditions of the site, within the scope of those guidelines, that would indicate the site is not suitable. If no such features or conditions can be identified, then lower-level suitability findings on the technical guidelines can be supported. The second objective is to determine whether additional information would be likely to change this conclusion. If not, then a higher-level suitability finding can be supported. If the uncertainties are such that the conclusion could change, then the objective is to identify issues that may provide a focus for testing during site characterization and that must be resolved before a higher-level finding can be supported. The technical guidelines are evaluated individually and the results of the evaluation of each guideline are discussed in Section 2.3

The evaluation of the Postclosure System Guideline determines whether the system performance requirements specified in the guideline can be met. This requires an integrated assessment of the issues identified in the technical guideline evaluations and other issues related to waste isolation and containment identified in the performance assessments, themselves. For example, many of the technical guidelines focus only on specific aspects of site performance, such as hydrology, which addresses the movement of water, or geochemistry, which addresses the movement of solutes in the water. Such distinctions are eliminated when these issues are considered together in the system guideline evaluation.

The evaluation of the system guideline involves system and subsystem performance assessments. These assessments are generally accomplished through the following types of analyses:

1. Identification of system performance measures

2. Development of models needed to evaluate the performance measures

3. Evaluation of the performance measures

4. Conduct of sensitivity and uncertainty analyses to identify critical model parameters and to evaluate the importance and role of uncertainties in site information.

These analyses are explained in the following paragraphs.

Identification of Performance Measures. Performance measures are the key variables in evaluating the qualifying conditions of the Postclosure Guidelines. These measures are derived from the performance criteria specified in the Postclosure System Guideline.

The regulations cited in the Postclosure System Guideline specify five performance measures:

1. 10,000-year cumulative release of radionuclides to the accessible environment ("cumulative-release" performance measure in 40 CFR 191.13)

2. Annual dose equivalent to the maximally exposed individual ("individual protection" performance measure in 40 CFR 191.15)

3. Concentrations of radionuclides in special sources of ground water ("ground-water protection" performance measure in 40 CFR 191.16)

4. Time of containment of radionuclides within waste packages ("waste-package containment period" performance measure in 10 CFR 60.113(1)(a)(ii)(A))

5. Rate of release of individual radionuclides from the EBS ("EBS release-rate" performance measure in 10 CFR 60.113(1)(a)(ii)(B)).

These performance measures and the associated regulatory criteria are provided in Table 2-1. These measures and criteria provide the standards for "waste containment and isolation," the phrase that is used throughout the Postclosure Guidelines. Thus, when the qualifying condition of a technical guideline specifies that a condition is to be "compatible with waste containment and isolation," this is interpreted to mean that the "specified site characteristics should be such that there is confidence that the performance criteria are likely to be met." The performance measures and criteria, and particular conditions that should be considered in their evaluation, are described more fully in the discussions of the postclosure performance objectives in the cited regulations and in DOE documents such as the SCP (DOE, 1988a) and the Performance Assessment Strategy Plan (DOE, 1990d).

Development of Performance Assessment Models. The models needed for performance assessments include representations of the site and engineered barriers, conceptual models for the processes that affect the radionuclide source term and transport to the accessible environment, scenarios for future states of nature, and computational models. The reliability of current information and uncertainties represented in these models, possible alternative models, and the sensitivities of performance assessment results to particular models are important considerations in site-suitability evaluations.

The most critical models for predicting the radionuclide source term appear to be the representation of the EBS and the host rock in the vicinity of the waste packages. Models for hydrologic, geochemical, and rock characteristics that affect EBS performance and models that address the

Table 2-1. Criteria For Acceptable Postclosure Performance

Performance Measure	Regulatory Standard	Acceptable Performance
Cumulative release (10,000-year release normalized by the EPA release limits)	40 CFR 191.13	<10% probability of exceeding 1; <0.1% probability of exceeding 10
Individual protection (Peak annual dose to the maximum individual)	40 CFR 191.15	<25 mrem to whole body; <75 mrem to any critical organ
Ground-water protection (Radionuclide concentrations in special sources of ground water)	40 CFR 191.16	<5 pCi/liter of Ra-226,228; <15 pCi/liter of alpha emitting radionuclides; <4 mrem per year from combined beta and gamma emitters
Waste-package containment period	10 CFR 60.113(a) ...(A)	>300 years[a]
EBS release of any radionuclide with inventory exceeding 10^{-8} of total 1,000-year inventory	10 CFR 60.113(a) ...(B)	$<10^{-5}$ of 1,000-year inventory per year[b]

[a]300 years or such other time between 300 and 1000 years as may be specified by the NRC.

[b]On a case-by-case basis, the NRC may specify some other criteria provided the EPA standards are met.

effects of heat and radiation produced by the waste on these characteristics are also expected to be important.

The most critical models for predicting transport to the accessible environment are those related to the transporting media (e.g., ground water or air in the unsaturated zone) and to the transport processes associated with these media. Site features and conditions associated with geohydrology, geochemistry, and rock characteristics will define components of these models that must be taken into account in addressing aspects of the performance assessments.

Models for disruptive processes and events that might affect performance are also critical to the assessments. These processes and events are defined in terms of scenarios that describe possible states of nature that may occur at the site during the next 10,000 years. Such scenarios of the future are developed on the basis of inferences drawn from evidence about the magnitude and recurrence intervals of past events and conditions and the processes that led to those events and conditions. While there may be many issues associated with the characteristics of the site, the most important of these for performance assessments are those associated with predicting future states of nature.

Another important consideration in assessing site suitability is the complexity of the site and the difficulty of representing the effects of site features, conditions, and processes in performance assessment models. If the conceptual models needed to represent site characteristics are very complex, it may be difficult to represent them numerically in computer codes. If there are alternative conceptual models, uncertainties are increased, especially if these alternative models are not incorporated explicitly in performance assessments. The degree of complexity may vary from location to location, and therefore may be an important consideration in evaluating site suitability.

Although quantitative assessments were considered, they did not provide the principal focus of this early site suitability evaluation. Ultimately, the evaluation of the suitability of the site will involve detailed, quantitative performance analyses to assess compliance with numerical criteria. These analyses will be based on conceptual models that are consistent with the information gathered during site characterization. Because it is too early in the site characterization program for such information and for having models that are fully developed, the Core Team did not rely heavily on quantitative performance models. (A good example is in the area of geohydrologic processes. Because the models in this area are at a relatively early stage of development, the Core Team did not consider it appropriate to rely heavily on them at this time.) Nevertheless, the Core Team did review the status of the quantitative assessments during their evaluation of the System Guideline. The results of this review and the evaluation of the System Guideline are presented in Section 2.4.

<u>Evaluation of Performance Measures</u>. These analyses use the models of site characteristics and other aspects of the repository system to determine the values of the performance measures. Results are used for a variety of purposes, such as comparison with regulatory criteria to determine compliance with those criteria, identification of information needs, development of design criteria, analysis of adverse impacts, and identification of mitigation measures, and site suitability evaluations.

Such analyses often entail quantitative analysis of empirical data, mathematical models of relationships between site features and conditions and site performance measures, and long-term computer projections of the performance of the potential repository. Such analyses may be based initially on subjectively determined inputs, which are later replaced by empirical data as site testing continues.

In other instances, performance measures are evaluated qualitatively, without the aid of mathematical models on the computer. When numerical models are not available, understanding developed through experience can be used to estimate possible effects of site characteristics on performance.

Regardless of whether performance evaluation is qualitative or quantitative, subjective judgment plays a significant role. In the quantitative case, subjective judgment is used to construct preliminary mathematical models and to decide whether those models are sufficiently accurate to make early judgments about suitability. As subjective inputs are replaced by empirical data, and as confidence is gained in models, there are still critical subjective judgments, such as the relevance of particular data sets. Therefore, expert judgment is critical throughout the performance evaluation process, whether quantitative models are used or not.

Other critical considerations are the uncertainty in model inputs, in the appropriateness of conceptual models, and, consequently, in the projections of performance. Again, this is an inherent and persistent subjective judgment that may diminish in importance but will never be eliminated. In fact, the concept of higher-level findings allows for residual uncertainties about performance when making judgments about the suitability of the site.

Conduct of Sensitivity and Uncertainty Analyses. These analyses are critical to site-suitability evaluations because they can identify attributes of the site important to performance. The analyses must address uncertainties in models, including uncertainties in the parameters of a particular model, in alternatives to models, and in the extrapolation of current conditions to future states of nature.

Analysis of sensitivities and uncertainties associated with particular site features and conditions was conducted as part of the evaluation of individual technical guidelines. Following the general approach described at the end of Section 1.2.4, the evaluation determined if there are specific features or conditions that could lead to violation of any performance criteria. (This was determined using a performance model or using judgment if an appropriate quantitative model was not available.) If performance criteria could be violated due to the presence of a particular feature or condition, the likelihood of such features and conditions was judged and then used to rank the potential importance of the uncertainty, or the importance of the "issue," associated with those features and conditions.

The results of the technical guideline evaluations are presented in Sections 2.3.1 through 2.3.9. Section 2.4 provides the results of the System Guideline evaluation and a summary of the Postclosure Guideline evaluations.

2.3 EVALUATION OF THE POSTCLOSURE TECHNICAL GUIDELINES

The following sections present the conclusions of the Core Team for the Postclosure Technical Guidelines.

2.3.1 GEOHYDROLOGY TECHNICAL GUIDELINE

2.3.1.1 Statement and Discussion of Qualifying and Disqualifying Conditions

Qualifying Condition [10 CFR 960.4-2-1(a)]: "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."

Disqualifying Condition [10 CFR 960.4-2-1(d)]: "A site shall be disqualified if the pre-waste-emplacement groundwater 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."

Discussion. The qualifying condition for geohydrology emphasizes the need for compatibility of present and expected characteristics of the geohydrologic setting with waste containment and isolation. In doing so, this guideline requires a sufficient understanding of current (nominal) and future geohydrologic conditions at the site to establish the compatibility of these conditions with waste containment and isolation. Waste containment and isolation are defined by the Postclosure System Guideline (Section 2.4) in terms of the regulatory performance objectives for cumulative releases to the accessible environment and for releases from the engineered barrier system (EBS).

The intent of the disqualifying condition is to require an evaluation of the performance of the natural geologic setting as a component of the multiple-barrier system. The multiple-barrier system is intended to provide reasonable assurance that the total system performance standard will be met. The 1,000-year travel time in the disqualifying condition differs with the 10 CFR 60.113 criterion on travel time to the accessible environment by the words "and significant." According to Section IV(B)(3) of the Supplementary Information for 10 CFR 960, these words were added to 10 CFR 960.4-2-1 to avoid disqualifying an adequate site on the basis of the potential for insignificant fast pathways before adequate site characterization and before the extent of the disturbed zone and the boundaries of the accessible environment are accurately defined. The inclusion of the "disturbed zone" in this condition is intended to simplify ground-water travel-time calculations by eliminating from consideration the region where complex temporal changes in physical and chemical properties are likely to occur as a result of repository construction and waste emplacement.

The wording in the disqualifying condition is open to interpretation with regard to definitions for "groundwater travel time" and "path of likely and significant radionuclide travel." Freeze et al. (1987) suggest that for the Yucca Mountain site, the ground-water travel-time definition should incorporate the concept of molecular diffusion to account for the exchange of solutes and water between the relatively immobile water in the pores and water flowing in the fractures. Additionally, they note that the regulation implicitly assumes that one or more distinct paths of ground-water flow with a unique travel time can be identified. The size of the potential repository and the complexity of the geology will lead to distributed sources, multiple pathways, and uncertainty as to the most critical path. Finally, Freeze et al. (1987) note that the regulation does not recognize any concept of acceptable risk with respect to the criterion. Some finite probability of failing to meet the 1,000-year criterion will always exist. Sinnock (1986) discuss the significance of using multiple realizations for developing a statistical representation of ground-water travel time that incorporates the uncertainty associated with the distribution of hydrogeological properties. They represent their results in a cumulative distribution function that is used to identify the probability of the fraction of likely and significant paths that will not meet the travel-time criterion. Yeh and Stephens (1988) discuss the importance of scale and sources of uncertainty relative to the definition of ground-water travel time. They propose defining a threshold value for mass flux over a specified area of the accessible environment as a more significant criterion.

For purposes of this site suitability evaluation, ground-water travel time is defined as the cumulative displacement of a tracer particle divided by the ground-water velocity along a specified path of likely flow. "Paths of likely and significant radionuclide travel" are defined to be those identifiable flow paths along which water bearing radionuclides released from the EBS could travel from the disturbed zone to the accessible environment.

2.3.1.2 Approach for Geohydrology Evaluation

This section first identifies the technical issues related to the Geohydrology Guideline and then discusses the approach for resolving the issues.

2.3.1.2.1 Identification and Basis for Geohydrology Technical Issues

The assessment of the Postclosure Geohydrology Guideline emphasizes an evaluation of issues related to the qualifying and disqualifying conditions. The identification of issues was based on the Environmental Assessment (EA) (DOE, 1986), the conditions stated in the guideline, recommendations from expert panels and peer review teams, and the current understanding of the technical issues related to postclosure geohydrology. Because the most likely mechanism for radionuclide release to the accessible environment after repository closure is transport by ground water, the technical issues concern specific conditions (e.g., interconnected flow paths and sources of water) that must be present before significant affects on waste isolation and containment can occur. The issues identified are interrelated and appear consistent with the principal assumptions made in the EA about the geohydrologic system at Yucca Mountain.

- Technical Issue 1: Conditions for Sustained Flow

  Do conditions within the geohydrologic system currently exist or are conditions likely to exist in the future that could provide pathways capable of sustaining sufficient flow to affect waste containment and isolation?

• Technical Issue 2: Expected Travel Time

Do conditions exist at the site such that 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 path of likely and significant radionuclide travel?

2.3.1.2.2 Information or Actions to Resolve Geohydrology Issues

Resolution of Technical Issue 1: Conditions for Sustained Flow

The resolution of Issue 1 requires a coupling of site characterization data with modeling results (a) to identify and characterize flow paths that may impact waste isolation and containment, (b) to estimate the spatial distribution and flow capacity of these paths, and (c) to identify mechanisms for initiating and sustaining flow in these paths. The concept of "sustained" used in this evaluation implies temporal durations and spatial continuity of flow that have the potential to adversely affect waste containment and isolation. The key technical elements related to this issue are (a) the presence or absence of interconnected flow paths that can accommodate sufficient volumes of water to interact with the waste packages and transport radionuclides to the accessible environment and (b) the ability to quantify these conditions in models that correctly approximate the geohydrologic system.

Flow paths are defined as relatively high-conductivity zones of concentrated flow (i.e., "fast" flow paths) that could significantly influence waste containment and isolation. These paths may be continuous or discontinuous and may exist over a variety of scales from zones of intense fracturing associated with faulting to channeling within a single fracture. In addition to faults and fractures, other physical features, such as connected, high-conductivity zones within the matrix, may act as flow paths. They can be activated by various processes or features, such as high-intensity, episodic infiltration events; topographic irregularity; soil-surface heterogeneity; flow into surface-connected fractures; flow into and through major faults; and perched-water conditions. Sources for sustaining flow in these paths are essential if they are to affect waste isolation and containment.

The spatial and temporal distribution and magnitude of infiltration into the system may be the most important independent parameter influencing flow-path development. Rapid infiltration associated with transient pulses of water appears to occur in the near-surface fracture systems at Yucca Mountain. Several mechanisms may attenuate and redistribute these pulses at depth, including variations in the unsaturated hydraulic characteristics and degree of fracturing associated with the nonwelded and bedded tuffs that are located above and below the repository horizon. The processes controlling mass transfer of the vapor phase may also affect infiltration characteristics.

The complexity of the geohydrologic system will have a significant impact on the factors that must be incorporated in models that approximate flow and transport processes at the site. A geohydrologic model of the site must consider the existence of both the fractures and the matrix, the saturation conditions, the flow conditions (i.e., steady-state or transient), and the significance of boundary conditions to accurately assess the importance of these conditions on waste containment and isolation.

Resolution of Technical Issue 2: Expected Travel Time

The information required to resolve this issue will be acquired to assess the compatibility of the geohydrologic setting with waste isolation and containment (Issue 1). The key technical element related to this issue is calculating a ground-water travel time using a model that incorporates the processes and mechanisms within the geohydrologic setting that lead to pathways of likely and significant radionuclide travel.

2.3.1.3 Status of Geohydrology Current Information

2.3.1.3.1 Summary of Environmental Assessment Findings for Geohydrology

The Postclosure Geohydrology Guideline includes one qualifying condition, one disqualifying condition, five favorable conditions, and three potentially adverse conditions. Table 2-2 provides statements of each of these conditions as well as the suitability findings from the EA (DOE, 1986). The EA states that there is currently no evidence that the site will not meet the qualifying condition (Level 3 finding) and that the evidence does not support a finding that the site is disqualified (Level 1 finding). There is considerable uncertainty in the data used to support these conclusions; however, where possible, the analyses were based on conservative assumptions.

The EA summarized the characteristics of both the saturated and unsaturated zones and reviewed the parameters required to evaluate the dominant processes and mechanisms that are likely to influence waste containment and isolation. This summary provided the basis for evaluating each condition associated with this guideline and for drawing conclusions relative to findings as they pertain to the qualifying and disqualifying conditions. The primary assumptions and data uncertainties associated with the EA were related (a) to the amount of recharge and the related ground-water flux through the unsaturated zone and (b) to the dominant mechanisms that control water percolation in the unsaturated tuffs. To compensate for the uncertainty in the information that existed at that time, conservative assumptions were made to bound the probable range of hydraulic behavior at the site.

According to the EA, the nature and rates of the hydrologic processes active at Yucca Mountain during the Quaternary Period were influenced by cyclic fluctuations in precipitation and a possible trend of increasing aridity (Winograd and Doty, 1980). The Quaternary Period was characterized by wetter, cooler pluvial periods alternating with dryer, warmer interpluvial periods. Thus, at times, changes in hydrologic phenomena were related to increases in available moisture; at other times, changes were associated with drying conditions. The most recent climatic trend that has led to the conditions observed today results from the shift from pluvial to interpluvial conditions. Winograd and Doty (1980) provide evidence, based on calcitic

Table 2-2. Summary of Environmental Assessment Findings for Geohydrology (DOE, 1986)

Condition	DOE Finding
QUALIFYING CONDITION	
The present and expected geohydrologic setting of a site shall be compatible with waste containment and isolation. The geohydrologic setting--considering the characteristics of, and the processes operating within, the geologic setting--shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.	Existing information does not support the finding that the site is not likely to meet the qualifying condition (Level 3). Radionuclide release is expected to be less than one part in 100,000 of the 1,000-year inventory; ground-water flow time is likely to be more than 10,000 years; the low magnitude of ground-water flux limits potential release of radionuclides.
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.	Existing information does not support the conclusion that the site is disqualified.
FAVORABLE CONDITIONS	
1. Site conditions such that the pre-waste-emplacement ground-water travel time along any path of likely radionuclide travel from the disturbed zone to the accessible environment would be more than 10,000 years.	The evidence indicates that this condition is present at Yucca Mountain.
2. The nature and rates of hydrologic processes operating within the geologic setting during the Quaternary would, if continued into the future, not affect, or would favorably affect, the ability of the geologic repository to isolate the waste during the next 100,000 years.	The evidence indicates that this condition is not present. Climate changes could cause changes in the water table position and increase flux. These are expected to affect, but not significantly reduce, isolation potential in the next 100,000 years.

Table 2-2. Summary of Environmental Assessment Findings for Geohydrology (DOE, 1986) (continued)

Condition	DOE Finding
FAVORABLE CONDITIONS (continued)	
3. Sites that have stratigraphic, structural, and hydrologic features such that the geohydrologic system can be readily characterized and modeled with reasonable certainty.	Evidence indicates that this condition is not present. The geology is complex. There are no known features that would prevent the site from being characterized and modeled. Available data are insufficient to model the site with reasonable certainty.
4. Applies only to disposal in the saturated zone.	Condition does not apply to Yucca Mountain.
5. For disposal in the unsaturated zone, at least one of the following pre-waste-emplacement conditions exists:	Evidence indicates that three of the five subconditions are present.
i. A low and nearly constant degree of saturation in the host rock and in the immediately surrounding geohydrologic units.	The degree of saturation in the host rock and surrounding geohydrologic units is spatially variable. Therefore, this subcondition is not present.
ii. A water table sufficiently below the underground facility such that the fully saturated voids continuous with the water table do not encounter the host rock.	The host rock contains no fully saturated voids that are continuous with the water table. Therefore, this subcondition is present.
iii. A geohydrologic unit above the host rock that would divert the downward infiltration of water beyond the limits of the emplaced waste.	The bedded tuffs above the densely welded host rock may divert pulses of water, but not necessarily beyond limits of emplaced waste. Therefore, this subcondition is not present.
iv. A host rock that provides for free drainage.	The host rock is expected to be freely draining. This subcondition is present.

Table 2-2. Summary of Environmental Assessment Findings for Geohydrology (DOE, 1986) (continued)

Condition	DOE Finding
FAVORABLE CONDITIONS (continued)	
v. A climatic regime in which the average annual historic precipitation is a small fraction of the average annual potential evapotranspiration.	Precipitation in the area is about 20 percent of the potential evapotranspiration. Therefore, this subcondition is present.
POTENTIALLY ADVERSE CONDITIONS	
1. Expected changes in geohydrologic conditions--such as changes in the hydraulic gradient, the hydraulic conductivity, the effective porosity, and the ground-water flux through the host rock and the surrounding geohydrologic units--sufficient to significantly increase the transport of radionuclides to the accessible environment as compared with pre-waste-emplacement conditions.	The evidence indicates that this condition is not present. Expected changes in geohydrologic conditions are not likely to significantly increase the transport of radionuclides.
2. The presence of ground-water sources, suitable for crop irrigation or human consumption without treatment, along ground-water flow paths from the host rock to the accessible environment.	The evidence indicates that this condition is present. Ground-water sources suitable for crop irrigation or human consumption are present along ground-water flow paths, although resource potential is small.
3. The presence in the geologic setting of stratigraphic or structural features--such as dikes, sills, faults, shear zones, folds, dissolution effects, and brine pockets--if their presence could significantly contribute to the difficulty of characterizing or modeling the geohydrologic system.	The evidence indicates that this condition is present. Fractures, fault zones, and dikes could contribute to the difficulty of characterizing and modeling the system.

fracture fillings and lake bed deposits, that discharge from regional ground-water systems at one time may have occurred as much as 50 m higher than the modern location. Using assumptions that could lead to results that are more detrimental to performance than actually expected, Czarnecki (1985) indicates a potential for the water table to rise by as much as 130 m above the present level. Cyclic fluctuations in climate are expected to continue, and pluvial conditions are likely to return over the next 100,000 years.

The general stratigraphic and structural features of Yucca Mountain and vicinity (Lipman and McKay, 1965; Scott and Bonk, 1984; and Spengler and Chornack, 1984) are well known, as a result of detailed geologic mapping and drilling. The EA acknowledges that stratigraphic and structural relationships appear complex. Rocks range in age from Precambian through Holocene, and many periods of structural deformation have affected these older rocks. North-striking, high-angle extensional faults displace the eastward dipping Tertiary volcanic rocks both east and west of the potential site, and smaller faults intersect the site itself (Bath and Jahren, 1984; Scott and Bonk, 1984).

The conceptual model used in the EA to describe flow in the unsaturated zone (Montazer and Wilson, 1984) combines information on the geologic structure and stratigraphy (Scott et al., 1983) with site-specific data collected from core samples and boreholes. This conceptual model considers the significance of flux on fracture-matrix interactions and on the effectiveness of capillary barriers at the contacts between the nonwelded and welded units qualitatively. The conceptual model identifies conditions that could promote lateral flow that would divert downward infiltration of water. These conditions include the presence of dipping (nominally 3 to 8 degrees) potentially anisotropic units of contrasting properties, the effects of which are enhanced by the development of capillary and permeability barriers. Postulated lateral flow could move down-dip until reaching structural features that divert flow downward through the unsaturated section.

Hydrologic testing of the saturated zone (Craig and Robison, 1984; Lahoud et al., 1984; and Rush et al., 1984) included pumping tests over large intervals and packer-injection tests over isolated intervals within three holes. The results of these tests indicate that flow occurs mainly through fractures in the welded tuffs and that productive intervals are controlled primarily by the distribution of permeable fractures intercepted by the hole and not by stratigraphic position in the densely welded tuffs. Fourteen additional holes were drilled to provide data on the altitude of the water table (Robison, 1984). Although perched water was not encountered in the one unsaturated-zone borehole (USW UZ-6) drilled within the proposed repository boundary, evidence of perched water may have been observed in two boreholes (USW UZ-1 and USW H-1) that are adjacent to the Yucca Mountain site. Drilling was terminated at USW UZ-1 because of water inflow into the borehole. However, a water sample collected after drilling ceased contained polymers identical to those used for drilling USW G-1, which is located about 305 m away (Whitfield, 1985). USW H-1 was drilled using air-foam as drilling fluid (Rush et al., 1984), which may be the source for fluids seen to be apparently draining from fractures into the borehole observed in a television-camera log of this borehole.

A stochastic approach, which incorporated conservative assumptions as part of the flow model, was used to evaluate the distribution of ground-water travel time (Sinnock, 1986) for the EA evaluation. The travel time consists of the sum of the travel time through the unsaturated zone and the travel time through the saturated zone to the accessible environment. The calculated mean travel time was 43,405 years (a range of 9,345 to 80,095 years), which significantly exceeds the 10,000-year requirement for the favorable condition and the 1,000-year requirement for the disqualifying condition. Sinnock (1986) identify a number of major assumptions that underlie these calculations, which require site characterization data for verification. The calculated travel time through the unsaturated zone was based on one-dimensional simulations assuming steady-state flow conditions and a flux of 0.5 mm per year. Fractures were assumed to carry flow only if the rock became locally saturated. The EA noted that the assumption of steady-state flow may not be valid under specific circumstances where precipitation events may saturate surface rocks and result in fracture flow. Similar calculations performed using a flux of 1.0 mm per year resulted in a mean travel time of 21,045 years (a range of 3,700 to 45,190 years).

The mean travel time calculated for the saturated zone is 140 years, using a simple analytical approach. The saturated-zone analyses relied on an estimate of effective porosity that was considered reasonable for fracture flow because saturated flow is thought to be fracture-dominated. However, this resulted in travel times that may be an order-of-magnitude less than would be expected using less conservative values of effective porosity (i.e., including both fractures and matrix).

2.3.1.3.2 Review of Geohydrology Information Acquired since the Environmental Assessment

A limited amount of new site-specific data that relate to the Post-closure Geohydrology Guideline has been collected and published since the EA. Continued evaluation and reinterpretation of existing data, coupled with natural-analogue studies, laboratory experimentation, and analyses, have provided additional new insight to and understanding of the dominant processes in and characteristics of the geohydrologic setting at Yucca Mountain. Most of this information emphasizes the unsaturated zone and the processes and mechanisms that are likely to influence flow and transport within this zone. A limited amount of new work has also been completed on specific aspects of the saturated zone. This new work, also summarized in the following discussion, has emphasized mainly the large hydraulic gradient located beneath Yucca Mountain north of the potential repository site.

Numerous publications exist that provide a general overview of the geohydrologic system at Yucca Mountain. A summary of site-specific geohydrologic data and information is available in the Site Characterization Plan (DOE, 1988a), the Yucca Mountain Project Bibliography 1988-1989 (DOE, 1990i), and references contained within the semiannual Yucca Mountain Project Technical Status Reports. Two recent documents important to understanding the issues specific to the unsaturated zone are currently in review. Wang and Narasimhan (1990) discuss important hydrological issues relating to the movement of water through the partially saturated fractured tuff rock system at Yucca Mountain. Narasimhan and Wang (1990) provide a comprehensive summary of the processes, mechanisms, and parameters governing unsaturated flow. Buscheck et al. (1991a,b) discuss the primary attributes of the nominal hydrologic flow system at the Yucca Mountain site as it relates to performance of the EBS with specific emphasis on episodic, nonequilibrium fracture-matrix flow. A commentary on technical issues specific to the site and the adequacy of the current data base and level of understanding for the unsaturated zone is provided in the Draft Peer Review Record Memorandum (Freeze et al., 1991).

The literature contains numerous references to sources on the applications of modeling to investigate fracture-flow processes in the unsaturated zone. Wang (1991) reviews the advances in fracture-flow modeling and understanding over the past several years. The National Research Council (1990) summarizes the current state of conceptual understanding of hydrogeologic systems and the ability to predict performance objectives. The U.S. Nuclear Regulatory Commission (NRC) has supported an active program attempting to identify the characterization and modeling problems associated with an unsaturated-tuff repository site (Rasmussen and Evans, 1987; Evans and Rasmussen, 1991).

The conceptual model for saturated-zone flow considers the flow system to be controlled principally by the relatively time-invariant lithologic and structural features of the geologic formations and driven principally by gravity flow from recharge to discharge areas (DOE, 1988b). Yucca Mountain and the controlled area for the potential repository are within the Alkali Flat-Furnace Creek Wash ground-water system. Flow within the volcanic rocks underlying the site is southward to the Amargosa Desert, continuing southward and mixing with inflow from other areas in basin-fill deposits to discharge principally at Alkali Flat, about 45 miles south of the site. Some of the discharge in the Furnace Creek Wash area of Death Valley may be derived from water in the Amargosa basin-fill deposits, but other sources probably provide much of the discharge by way of regional flow in the thick Paleozoic carbonate rocks that underlie the region. These carbonate rocks are believed to be present beneath the Yucca Mountain site also, but the hydraulic potential within them is greater than that in the volcanic rocks (Craig and Robison, 1984). Therefore, if flow occurs vertically, it is from the deep carbonates upward into the volcanics.

Fridrich et al. (1991) discuss a hydrogeologic model for the saturated zone that takes into account the large hydraulic gradient located to the northeast of the Yucca Mountain site. They attribute the gradient to a buried fault that allows flow from the tuff aquifer to the north to be captured by the more permeable carbonate aquifer that underlies the central and southern parts of the Yucca Mountain site. They also propose a model based on geometric arguments that suggests perched water may exist within the Topopah Spring Member. To evaluate this and other hypotheses proposed for the hydraulic gradient, they suggest drilling a deep borehole into the base of the Crater Flat tuff or preferably into the Paleozoic rocks in the center of the large gradient. Sinton (1989) summarizes five alternative models that may contribute to the hydraulic gradient. Czarnecki (1989b) reports results of analyses that suggest a potential rise in water-table altitude as a result of increases in transmissivity across the hydraulic barrier.

In addition to this general information, a significant volume of literature has been published that addresses the key technical elements relevant to Issues 1 and 2. The following material emphasizes recent work germane to the specific elements associated with the geohydrology guideline. This work continues to support the lower-level suitability findings presented in the EA that the geohydrologic setting of the site is not incompatible with waste isolation and containment.

Information Relevant to Issue 1: Conditions for Sustained Flow

Information that addresses the key technical elements related to this issue has emphasized (1) flow-path occurrence and characteristics, (2) processes controlling the attenuation and redistribution of water entering the unsaturated zone, and (3) developing confidence in the modeling capabilities describing fracture-matrix interactions in the unsaturated zone.

(1) Flow-Path Occurrence and Characteristics. Evidence supporting the existence of flow paths extending to depth has been reported for several locations characterized by unsaturated fractured rock. At the Yucca Mountain site, anomalously high values of chlorine-36 and tritium have been encountered at depths of hundreds of meters (Flint, 1989; Freeze et al., 1991; Norris, 1989). Tunnels in Ranier Mesa (including G-tunnel), located to the north of Yucca Mountain, encounter fractures that transmit water (Freeze et al., 1991). If the average annual recharge at Yucca Mountain is low, then net infiltration by way of preferential flow paths may be the most important infiltration mechanism in the region (Freeze et al., 1991). Sass et al. (1988) report a temperature profile for well UE-25 a#7 in Drillhole Wash that was modified significantly during a locally heavy rainfall to depths approaching 150 m. They attribute this modification to significant lateral infiltration within the fractured, densely welded tuff of the Topopah Spring Member. Responses to precipitation events have also been noted in mine tunnels near the Apache Leap tuff site in Arizona within weeks of the precipitation events (Evans and Rasmussen, 1991). The mine tunnels lie hundreds of meters below the surface.

Nitao (1991), Buscheck and Nitao (1991a), Nitao and Buscheck (1991), and Buscheck et al. (1991a) have accounted for variations in fracture and matrix porosities in a discrete fracture-matrix model, which they used to investigate the flow response of unsaturated tuffs under a wide range of fluxes. Their results indicate that fracture flow occurs as a transient phenomenon that is influenced by matrix wetting diffusivity, fracture aperture, the specified flux or ponded condition, and the event duration. Critical fluxes and apertures calculated for the unsaturated units at Yucca Mountain (Nitao, 1991) indicate that fracture-dominated flow will be greatest in the low permeability, welded units and in the zeolitized, nonwelded Calico Hills unit. Critical fracture apertures for sustaining fracture flow in these units are on the order of 10 μm. For the vitric, nonwelded units relatively large fracture apertures, on the order of hundreds of microns, are required for sustaining fracture flow because of high matrix diffusivities. Nitao (1991) emphasizes that these observations are based on hypothetical conditions, assuming sufficiently high fluxes and throughgoing fractures, which should be evaluated during site characterization.

Results of analyses performed to investigate the conditions required to initiate and sustain flow paths using different conceptual models indicate that for an applied flux of less than 0.5 mm per year, no fracture flow could be sustained (Barnard and Dockery, 1991a). To sustain flow in these analyses, the flow path requires saturations significantly higher than the areally averaged conditions presently observed at the site. Similarly, if the flow paths are saturated, they are capable of sustaining rapid flow for considerable distances over a short time interval.

The inherent natural heterogeneity of a geologic system may contribute to the development of preferential flow paths. The theoretical development of differential equations designed to describe flow and transport through heterogeneous, unsaturated porous media has been well documented (e.g., Gelhar, 1986; Dagan, 1987). These theories have only recently been applied to field-scale experiments in soil (Nicholson et al., 1987). Others have used laboratory experiments (e.g., Glass, 1990) to better understand the conditions that lead to flow channeling. Of significant interest to the suitability of the Yucca Mountain site is the scale at which heterogeneities affect site performance. The potential for generating fast flow paths as a result of large-scale heterogeneities (i.e., dipping hydrostratigraphic layers of contrasting properties that divert and concentrate flow) is well-documented (e.g., Prindle and Hopkins, 1990). Dykhuizen and Eaton (1991) report that heterogeneities on a submeter scale can induce small-scale flow channeling that significantly increases mechanical dispersion of flow across a one-meter domain.

Gauthier et al. (1991) evaluated the consequences of fracture-controlled flow using simplified models. A radionuclide source term was estimated, as was radionuclide transport; both estimates were based on an assumption of constant flux over a given area. The consequences of this analysis are a function of the number of canisters contacted by the fracture-controlled flow and the amount of water available to dissolve the waste form. Releases calculated for 100 µm flow apertures indicate that as the number of fractures conducting flow decreases, the releases decrease for a constant flux, even if the fractures carry a large volume of water. For apertures larger than 125 µm, the probability of water intersecting canisters decreases, and releases to the water table decrease. In terms of repository performance, this analysis indicates the worst case is for a large number of fractures to be flowing, which increases the number of canisters contacted and the amount of waste dissolved.

(2) Processes Controlling Attenuation and Redistribution of Infiltrating Water. Field evidence (Flint, 1989; Norris, 1989) suggests that the highly fractured welded tuffs exposed to surface infiltration at Yucca Mountain are capable of transmitting water pulses to significant depths. If these pulses interact with the waste package and can be sustained for significant time periods, they may represent paths of likely and significant radionuclide travel. Conversely, if the pulses are attenuated and the fluids redistributed within the matrix, minimal impact on waste containment and isolation is likely.

Calculations by Nitao and Buscheck (1989) support the idea of a wetting front in fractures extending beyond that in the matrix under certain conditions constrained largely by the availability of water. Matrix hysteresis may also enhance fracture flow (Montazer and Wilson, 1984; Niemi and Bodvarsson, 1988). Matric suction also influences flow in unfractured, nonwelded media. Dykhuizen and Martinez (1991) present results from an analytical solution for a spatially periodic but steady point-source infiltration. The results allow approximation of the minimum thickness required to dampen spatial variations in infiltration given the alpha parameter assumed for the medium and the spacing of the point sources. Their results emphasize the importance of understanding the spatial variability in net infiltration at Yucca Mountain. Martinez and McTigue (1991) analyze steady infiltration from a strip source and report that, when the water table is deep, moisture distribution beneath the source depends on the product of the alpha parameter assumed and the strip-source breadth. As this product decreases, lateral dispersion of fluid introduced at the source increases. Wang and Narasimhan (1990) performed calculations applying cyclic pulses of varying durations to a column of layered, fractured, welded, and nonwelded tuffs. They report that a large pulse capable of saturating and initiating fracture flow in the top layer of the Tiva Canyon fractured welded tuff is damped by the relatively large pore volume and material characteristics of the underlying nonwelded Paintbrush unit. Thus, only a small perturbation reaches the Topopah Spring Member. Analyses completed by Nitao (1991) and Nitao and Buscheck (1991) indicate that significant attenuation from matrix imbibition is expected to occur in the nonwelded units above and below the repository horizon. Their results indicate that large fracture apertures and prolonged ponding conditions would be necessary to sustain fracture flow within these units.

Another possible mechanism of attenuation is the formation of a capillary barrier at the interface of a low-porosity (welded; small pores) medium overlying a medium of relatively high porosity (nonwelded; large pores). This mechanism may be readily observable at distinct interfaces, as is described by Montazer and Wilson (1984). Many numerical calculations are based on a conceptual model that involves an abrupt change of material properties across an interface (Prindle and Hopkins, 1990; Barnard and Dockery, 1991b; Buscheck et al., 1991b). In reality, material interfaces may not be discrete, and the strength of a capillary barrier is uncertain. On a smaller scale of material heterogeneity within a unit, these barriers may still play a role.

The bulk hydraulic conductivity of the Paintbrush nonwelded unit may be anisotropic, with conductivity parallel to bedding 10 to 100 times greater than that in a direction normal to the bedding plane (Montazer and Wilson, 1984). Down-dip gravity flow, therefore, is expected to enhance lateral moisture redistribution within these units. Prindle and Hopkins (1990) used the anisotropy ratio as a parameter of variation in a sensitivity analysis. Their results showed lateral diversion occurs at very low infiltration and small anisotropy ratios.

Many two- and three-dimensional calculations, based on a conceptual model that involves a distinct interface between units of contrasting properties and dipping beds, exhibit lateral flow at the interface at some rate of infiltration (Rulon et al., 1986; Wang and Narasimhan, 1987; Prindle and Hopkins, 1990; Dykhuizen et al., 1991; Rockhold et al., 1990; Wang and Narasimhan, 1990; Barnard and Dockery, 1991b). The result is that flux is diverted down-dip until it either exits the domain or encounters a transmissive vertical zone that may divert flow toward the water table. This process could significantly influence waste containment, dependent on whether diversion is away from or toward the waste emplacement areas. The down-dip vertical zone has been treated as a no-flow seepage-face and as a column with material properties suggestive of a fault. Prindle and Hopkins (1990) varied a number of model parameters to examine their effects on the resulting distribution of flow within the two-dimensional domain. Various combinations of material properties and boundary conditions were capable of inducing lateral flow. Their results indicate that when lateral flow occurs within the Paintbrush tuff, the repository zone below is shielded from transient pulses.

Large-scale flow of air through the rock units at Yucca Mountain has been observed under ambient conditions (Weeks, 1987; Thorstenson et al., 1989). This observation has reinforced the understanding that mass-transfer processes in the unsaturated zone require consideration of two phases: a liquid phase and a vapor or gas phase. This flow is thought to be driven by the combination of topographic relief and temperature differences between the surface and subsurface, with lesser but significant contributions from barometric pressure fluctuations, aerodynamic effects of wind blowing over the mountain, and the effect on density of the humidity difference between rock, gas, and air. Gas flow occurs primarily through larger fractures with minimal liquid-phase effects in the fractures and essentially negligible matrix effects because of the relatively low gas pressure and temperature gradients in the fractures (Freeze et al., 1991).

Under postclosure conditions, the vapor phase is significant in three general areas: changes in the water balance of the system, migration of volatile contaminants such as carbon-14, and gas convection as a mechanism for the removal of heat away from the repository environment. Convective heat transfer could possible provide a mechanism both for drying the rock material above the repository and for buffering transient infiltration events. Preliminary simulations exploring this mechanism have been conducted by Zyvoloski (1990). The ramifications of vapor-phase transport on releases to the accessible environment and on the near-field environment is discussed further in the Postclosure System (Section 2.4), Geochemistry (Section 2.3.2), and Rock Characteristics (Section 2.3.3) guidelines.

(3) Fracture-Matrix Interactions. The flow regime at Yucca Mountain may represent a continuum of fracture-dominated flow, concurrent fracture-matrix flow, and matrix-dominated flow. These complex interactions are difficult to quantify in a model that correctly approximates the flow regime within the unsaturated zone. Fracture-matrix interaction may be defined as the transfer of fluids and solutes between a fracture or fracture network and the porous matrix. Wang and Narasimhan (1985) provide a conceptual basis for understanding processes governing fracture-matrix interactions as developed according to capillary-bundle theory. To date, studies conducted to better understand fracture-matrix interactions have focused primarily on developing conceptual models based solely on theoretical arguments. The resulting conceptual models generally incorporate a single-composite continuum approach, a dual porosity approach, or a discrete-fracture approach. These approaches are all predicated on simplifying assumptions that require continued evaluation. Under the flux conditions currently thought to exist

at the site, a single composite-continuum approach could provide a reasonable approximation of solute transport (Dykhuizen, 1991).

Under conditions of both steady-state and transient flow, flow paths in fractured rock will be controlled by the flow and transport characteristics of the fracture, by variability in matrix and fracture properties, and by fracture network connectivity (Glass and Tidwell, 1991). Large-scale modeling of relatively steady-state flow through a fractured medium at moderate-to-high pore pressures may allow the fractures and matrix to be treated as a single composite continuum (Dudley et al., 1988; Peters and Klavetter, 1988). Here, fractures and the matrix are represented simply as a bimodal pore-size distribution. Equivalent properties can be modeled in a variety of ways depending on the connectivity within and between the pore groups composing the fractures and matrix (Brutsaert, 1987; Mualem, 1976; Tyler and Wheatcraft, 1990). For the approach to be valid, however, conditions close to equilibrium pressure must exist across all pore groups in a controlled volume at all times.

For large-scale transient flow conditions, a different approach may be considered. Here, it is convenient to model the fractured porous media as two interacting, overlapping continua (Huyakorn et al., 1983; Pruess and Narasimhan, 1985; Updegraff et al., 1991). In this dual-porosity approach, interaction between fracture and matrix continua is modeled through a "leakage" term, which is a function of a variety of factors, such as the gradient between the continua, the ratio between continua properties, matrix-block geometry, and the surface-to-volume ratio of the blocks. Again, equivalent properties for both the fracture and matrix continua must be modeled, as well as the leakage or interaction terms.

Numerous studies have evaluated the diffusive coupling of the matrix pore system to fracture flow. These studies attempt to account for various geometries of the matrix blocks and the various aperture distributions that can be obtained in a single fracture. The former will cause slight differences in the diffusive coupling term in early times when the penetration depth of the moisture front is small and the geometry of the block does not result in significant deviations from a linear flow field (Neretnieks and Rasmuson, 1984). With time, the geometry of the block plays a more significant role (Zimmerman et al. 1990). Variability in aperture size will cause channeling of the flow in the fracture, which results in a much larger dispersive term for fracture flow and an altered equivalent permeability for the fracture-flow system (Brown, 1987). Flow channeling could also affect the diffusive coupling, but this effect has not yet been studied.

Studies of fracture-matrix interactions in unsaturated systems typically assume that the Richards' equation adequately describes flows locally, within and near fractures. The validity of this application on such a small scale needs to be determined. There is concern that the effect of any small-scale coatings, or material property variations, near the fracture surfaces will need to be incorporated (Pruess and Wang, 1987). Wetting and drying transients in unsaturated fractures and temporal changes in fracture coatings may greatly complicate the process. A model for transient unsaturated flows has been formulated by Zimmerman and Bodvarsson (1989). Other models that consider planar fractures include those of Martinez (1988), Nitao (1991), and

Nitao and Buscheck (1991). These allow analytical determinations of the conditions necessary for fracture flow to dominate. Experiments on natural unsaturated systems are not presently available to test these models.

Martinez and Dykhuizen (1988) and Dykhuizen and Eaton (1990) have recently studied the effect of fractures as internal boundaries on unsaturated flow in the matrix pore system. They found that the effect of fractures appears minimal. Alternatively, Russo and Reda (1988) subjected a full core to a cycle of wetting and drying. They noted that microfractures oriented transverse to the direction of flow impeded the migration of an imbibed wetting front and served as points of rapid dryout without drainage. Nitao and Buscheck (1989) noted that, under a constant pressure head boundary, the flux into a downward-inclined fracture was a nearly constant value, acting to a certain extent as a flow-rate regulating system.

Information Relevant to Technical Issue 2: Expected Travel Time

Several analyses have incorporated ground-water travel time as a performance parameter to investigate the sensitivity of the output to the input assumptions and in some instances to make preliminary estimates of the ground-water travel time as specified by the regulatory criterion (Prindle and Hopkins, 1990; Barnard and Dockery, 1991b; Sinnock and Lin, 1989). These simulations include many simplifying assumptions that should be evaluated during site characterization before full reliance can be placed on the travel-time calculations. The results of these analyses, in general, indicate that the flow of water through the unsaturated, low-permeability materials at Yucca Mountain is a very slow process relative to the performance periods specified in the regulations, particularly if the system is dominated by matrix flow. Expected values of ground-water travel time calculated using probabilistic simulations range from about 16,000 years to hundreds of thousands of years. Deterministic calculations performed for expected conditions at the site exhibit a similar range. Note, however, that the results presented below are highly contingent on the assumptions used in defining and subsequently performing the analysis. Preliminary results presented by Buscheck and Nitao (1991a) and Kaplan (1991) indicate that under certain conditions episodic fracture flow may move through the mountain on a very short time scale.

Prindle and Hopkins (1990) conducted a comprehensive sensitivity study to identify the types of flow behavior that influence travel time and to provide insight and understanding of the behavior of a highly constrained and simplified system through the identification of conditions that appear to result in abrupt changes to the performance parameters. They used one- and two-dimensional steady-state and transient flow models in their study and used a discrete-particle tracking technique to calculate the time for the ground water to travel from the potential repository horizon to the water table. No tortuosity of the flow path is assumed in either the rock matrix or fractures, which are represented as overlapping continua. In their study, ground-water travel time was used strictly to explore the complex behavior of the flow system being modeled. Results of a one-dimensional transient analyses indicate ranges of travel time from greater than 220,000 years for applied fluxes of less than 0.2 mm to as low as 400 years for applied fluxes of greater than 1.0 mm and fracture-dominated flow conditions. The presence or absence of zeolitic material and associated hydrologic properties strongly influenced the results for the higher flux conditions. Results of two-dimensional analyses indicate that ground-water travel times are greater than 100,000 years for an assumed flux of less than 0.2 mm. For an assumed flux of 0.5 mm, the ground-water travel time exceeds 2,000 years; however, where the assumed flux approaches 1.0 mm, fracture-dominated processes result in travel times of less than 1 year. As in the one-dimensional simulations, the presence of zeolitic materials with their associated properties greatly influenced results for the simulations using higher (> 0.5 mm) fluxes.

Barnard and Dockery (1991a) present results of steady-state calculations using the average-fastest-particle method. This method calculates the travel time for the particle that traveled the "fastest" path, either through the matrix or fractures, provided that path carried at least one percent of the total flow volume. For the assumed flux of 0.01 mm per year, the travel times from the repository to the water table were all greater than 2,900,000 years for the one-dimensional models. Results from the two-dimensional simulations ranged from 15,000 years to greater than 6,000,000 years for the same flux. Note that at these fluxes, all flow was matrix-dominated. The simplifying assumptions that formed the basis for this analysis are clearly stated.

Sinnock and Lin (1989) used estimates of ground-water travel time to identify those factors that significantly influence flow times based on the approach used in the EA. Their results indicate that travel times are most significantly influenced by flux, spatial distribution of hydraulic conductivity, and spatial correlation length of some select hydrologic parameters. They state that spatially variable surface infiltration, potential for lateral flow, and the concentration of flux in fault zones need to be investigated before a cumulative distribution function can be interpreted as representing the best estimate of flow times at the site. Additionally, they state that hydrologic data presently available are insufficient to perform reliable statistical analyses to establish the interdependencies of the relevant hydrologic properties.

Robinson (1990) suggests that fluid flow through the saturated zone may contribute significantly to the total ground-water travel time. He defined ground-water travel time as the time required for a conservative tracer to reach a concentration of 0.5 of the initial concentration. His results indicate that, for fluid flow times of 10 years and a matrix porosity of 0.05, the 1000-year ground-water travel-time requirement could be satisfied in the saturated zone alone.

2.3.1.4 Current Status of Geohydrology Technical Issues

Technical Issue 1: Conditions for Sustained Flow

A limited amount of new site-specific data has been collected since the EA was completed. These data indicate that transient pulses of liquid occur within the upper welded units at Yucca Mountain, although there is no information presently available to indicate their maximum depth of penetration or how long the pulses may be sustained. Results from analyses suggest that these events should be short-lived unless there is a significant volume of water available to sustain flow within multiple flow paths and that their impact on waste isolation and containment will be limited. Confidence in the models applied in these analyses is limited by a lack of site-specific data, and each analysis is based on many simplifying assumptions that should be verified using site-specific information. The uncertainties identified in the EA (i.e., amount of recharge and related flux through the unsaturated zone and the dominant mechanisms controlling percolation) are still relevant pending new site characterization data. Site-specific investigations are required to identify and characterize potential flow paths, to establish the spatial and temporal distribution and magnitude of infiltration, and to establish a representative data set that can be used to model the geohydrologic system. Resolution of this issue is closely tied to determining if a higher-level suitability finding can be supported for the qualifying condition for geohydrology.

Technical Issue 2: Expected Travel Time

The results of ground-water travel-time analyses indicate that for conditions expected at the site and for the assumption that matrix flow dominates, the travel times are likely to exceed 1,000 years along paths of likely and significant radionuclide travel. These analyses have been conducted, however, with a limited hydrologic data set using models that may not correctly approximate the dominant conditions operative at the site. Site-specific studies are required to identify and characterize potential flow paths, to establish the spatial and temporal distribution and magnitude of infiltration, and to establish a representative data set for modeling the geohydrologic system. Resolution of this issue is closely tied to determining if a higher-level suitability finding can be supported for the disqualifying condition for geohydrology.

2.3.1.5 Conclusions and Recommendation for Future Geohydrology Activities

Conclusions

The consensus of the Core Team is that evidence continues to support lower-level suitability findings for both the qualifying and disqualifying conditions for geohydrology. Site characterization is expected to provide the data necessary to evaluate the potential for conditions that are likely, collectively, to cause the site to fail to meet the performance criteria (e.g., fast flow paths with sufficient volumes to dissolve and transport waste to the accessible environment). There is no reason to believe that these conditions are ubiquitous at the site; however, substantial testing and analyses are needed to support a higher-level suitability finding.

Recommendations for Future Activities

The results of this evaluation have identified specific activities, within the context of the ongoing site characterization program (see Section 8.3.1.2, DOE, 1988a), that should be emphasized to provide information needed to assess site suitability. These activities relate to the technical elements in Issue 1 that address (a) flow path occurrence and characteristics; (b) processes controlling the attenuation and redistribution of water entering the unsaturated zone; and (c) developing confidence in the modeling capabilities describing fracture-matrix interactions in the unsaturated zone.

Site-specific data are required to understand and quantify, where possible, the mechanisms controlling the spatial and temporal distribution and magnitude of infiltration and the processes controlling the attenuation and redistribution of transient pulses of water. A representative hydrologic data set should be collected to establish the interdependencies of the hydrologic properties that control flow and transport within both the saturated and unsaturated zones. Spatial and temporal variations in the hydraulic characteristics and in the fracture characteristics associated with the welded, nonwelded, and bedded tuffs located above and below the repository horizon should be quantified. These data should be augmented with a coupled field and laboratory program that investigates the basic assumptions underlying the models used for the unsaturated zone and that evaluates plausible mechanisms for rapid flow through the unsaturated zone. The effects of fracture coatings, material property variations near the fracture surfaces, and the effects of wetting and drying transients should be studied as part of this integrated laboratory and field program. Chemical and environmental tracers and data techniques should be used as an independent means to estimate travel times and to develop confidence in the models that are used to simulate flow processes and mechanisms. Water chemistry data from both the unsaturated and saturated zones should be obtained to better understand and constrain the assumptions associated with chemical processes and gaseous flow in the unsaturated zone and to provide boundary conditions for modeling these processes. Additional hydrologic testing within the saturated zone should be considered to characterize the dominant processes controlling flow to the accessible environment. Existing water table holes and those proposed for the future should be used for additional hydrochemical characterization. With respect to redistribution of water and occurrence of flow paths in the unsaturated zone, the conditions under which perched water may occur or develop in the future merit careful attention. With respect to saturated-zone conditions, the large hydraulic gradient north and west of the potential repository site and the very small gradient beneath it requires understanding and evaluation. Continued efforts should be expended to develop a position on the appropriate definition and regulatory implication of ground-water travel-time requirements.

2.3.2 GEOCHEMISTRY TECHNICAL GUIDELINE

2.3.2.1 Statement and Discussion of the Qualifying Condition

Qualifying Condition [10 CFR 960.4-2-2(a)]: "The present and expected geochemical characteristics of a site shall be compatible with waste containment and isolation. Considering the likely chemical interactions among the 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."

Discussion. This guideline addresses site geochemical characteristics that could affect radionuclide containment by the engineered barrier system (EBS) and isolation by the natural barrier system. Gas phase and ground-water transport of radionuclides are to be considered in the application of the guideline. In addition to the qualifying condition, the guideline includes five favorable and three potentially adverse conditions, as discussed in Section 2.3.2.3.1.

The expression "geochemical characteristics" is a potential source of confusion in interpretating this guideline. The authors of the Environmental Assessment (EA) (DOE, 1986) took it to mean the specific characteristics addressed by the favorable and potentially adverse condition statements of this guideline, i.e., mineral alteration reactions and rates; conditions that promote radionuclide precipitation, diffusion, or sorption; and conditions that inhibit the formation of or immobilize particulates, colloids, and complexes. This set of geochemical characteristics may need to be expanded to adequately treat gas-phase transport of radionuclides.

2.3.2.2 Approach for Geochemistry Evaluation

The approach for evaluation of the qualifying condition for this guideline was based on an assessment of the geochemical characteristics and processes that could be expected to retard radionuclide migration in the far field of the geologic setting. Geochemical reactions of rock and water with materials of construction of the EBS and the waste form are treated in the Postclosure Rock Characteristics Guideline evaluation (Section 2.3.3).

2.3.2.2.1 Identification and Basis for Geochemistry Technical Issues

The concerns related to geochemistry of the Yucca Mountain site are covered by the following three issues:

Issue 1: Are all expected radionuclide species retarded by the geochemical characteristics of and processes operating at the Yucca Mountain site?

Compatibility with isolation in the context of this guideline means the presence of geochemical characteristics and processes that could provide adequate retardation of radionuclides. If the travel time of the transporting medium (e.g., ground water) is sufficiently long, no retardation is needed. If the travel time of the medium is fast, then some geochemical retardation may be necessary to ensure adequate waste isolation. Because the expected range of travel times for ground water currently includes a small number of fast flow paths to the accessible environment (See Section 2.3.1.3.2), the extant and expected geochemical characteristics and processes may permit compliance with the isolation requirements provided that sufficient retardation can be substantiated for key radionuclide species (i.e., cations, anions, complexes, colloids, and particulates) that could be problematic if the fast flow paths exist. The probability of sustained flow along fast flow paths remains an open issue. If confirmed, significant geochemical retardation could be required for some radionuclides to demonstrate that the site is compatible with waste isolation.

<u>Issue 2: Will anionic and colloidal radionuclide species occur? Will the migration of any anionic and colloidal species be retarded by the extant and expected geochemical characteristics and processes at the Yucca Mountain site</u>?

To facilitate an evaluation of the qualifying condition, the geochemical characteristics and processes may be classified according to whether they (a) are "compatible with" and "permit compliance" or (b) are incompatible and preclude compliance with the Environmental Protection Agency (EPA) limits regarding release at the boundary with the accessible environment (EPA limits). This evaluation focused on conditions and processes classified as incompatible and precluding compliance; the greatest uncertainty remaining in this regard is with respect to conditions and processes to retard anionic and colloidal species.

<u>Issue 3: Will the extant and expected geochemical characteristics and processes retard gaseous radionuclide migration</u>?

The geochemical fate of gaseous radionuclides transported by convection and diffusion is less understood and therefore less certain than the fate of water-transported ones. Greater knowledge is needed of geochemical characteristics and processes (e.g., solution, sorption, and exchange) that may act to retard the migration of this and other gaseous radionuclides along their likely flow paths to the accessible environment. See Sections 2.3.3 and 2.4 for further discussions of the gaseous radionuclide concern.

2.3.2.2.2 Information Required to Resolve Geochemistry Issues

Ongoing studies should satisfactorily resolve the remaining uncertainty regarding retardation factors and mechanisms affecting anionic and colloidal radionuclide species. These studies should be continued; no new initiatives are required.

Tasks focused on gaseous radionuclide flow and transport in porous, fractured media should be activated.

2.3.2.3 Status of Current Geochemistry Information

Current information includes that upon which the EA was based and the results obtained from investigations ongoing since the EA was published.

2.3.2.3.1 Summary of Environmental Assessment Findings for Geochemistry

The EA finding on the qualifying condition of this guideline was based primarily upon existing geochemical characteristics and processes operating within the geologic setting and their rate of change as predicted by the geologic record of the Quaternary. The effects of geochemical characteristics and processes on radionuclide transport by ground water were considered in the evaluation. Unsaturated-zone waste emplacement, it was argued, would aid engineered barrier performance by postponing ground-water reactions with the materials of construction of the EBS. The EA findings are summarized in Table 2-3.

2.3.2.3.2 Review of Geochemistry Information Obtained since the Environmental Assessment

There is an overall strategy for evaluating the efficacy of the geochemical natural barrier to radionuclide transport by ground water at Yucca Mountain. The strategy seeks to identify likely flow paths for each radionuclide and to predict which processes and mechanisms may act to affect the length of time it would take for these radionuclides to reach the accessible environment.

Two processes figure centrally in retardation by the geochemical barrier: (1) precipitation and (2) sorption by minerals along transport pathways. Sorption may occur as a result of several mechanisms, including ion exchange and surface complexation. Knowledge of mineral distributions along likely flow paths of water to the boundary with the accessible environment will allow a determination of the extent to which precipitation and sorption may occur. Molecular diffusion from fast transport pathways into the surrounding rock matrix also will slow the rate of travel of all species, i.e., ions and complexes. Species that do not precipitate or sorb readily, however, may migrate in less time than ground water when coupled with preferred flow paths; speciation information is essential to reach conclusions about the likelihood of rapid transport. Radiocolloids, should they form, may be retarded by filtration. Predicting the likelihood of colloid formation and the effectiveness of filtration is a product of knowing the genesis and character of the colloids and their likely flow paths. Preferential flow paths also may hasten the transport of unfiltered colloidal species.

An element-by-element investigation of flow paths and transport mechanisms would be prohibitively expensive and time consuming. The flow paths of interest are the set of most likely paths to the boundary with the accessible environment. The composition of high-level waste expected to be emplaced in a potential repository at Yucca Mountain has been analyzed by several investigators (Oversby, 1987; Kerrisk, 1985). This composition has been categorized in terms of the amount of each radionuclide contained within

Table 2-3. Summary of Environmental Assessment Findings for Geochemistry (DOE, 1986)

Condition	DOE Finding
QUALIFYING CONDITION	
1. 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.	Existing information does not support the finding that the site is not likely to meet the qualifying condition (Level 3): releases to accessible environment are expected to be nearly zero for 10,000 years; unsaturated emplacement zone has benign chemistry and extremely low water flux, which are expected to aid engineered barrier performance.
FAVORABLE CONDITIONS	
1. The nature and rates of the geochemical processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years.	The evidence indicates that this favorable condition is present at Yucca Mountain: sorptive minerals (zeolites) were present in the tuff at Yucca Mountain throughout the Quaternary time; they are still present and are expected to contribute to isolation over the next 100,000 years.
2. Geochemical conditions that promote the precipitation, diffusion into the rock matrix, or sorption of radionuclides; inhibit the formation of particulates, colloids, inorganic complexes, or organic complexes that increase the mobility of radionuclides; or inhibit the transport of radionuclides by particulates, colloids, or complexes.	The evidence indicates that this favorable condition is present at Yucca Mountain: geochemical properties are expected to promote matrix diffusion; zeolites along flow paths will sorb radionuclides; retardation processes that would decrease the chemical absorption, and organic complexes that would increase mobility are not present; particulates and colloids may be filtered by tuffs, thereby inhibiting transport.

Table 2-3. Summary of Environmental Assessment Findings for Geochemistry (DOE, 1986) (continued)

Condition	DOE Finding
3. Mineral assemblages that when subjected to expected repository conditions, would remain unaltered or would alter to mineral assemblages with equal or increased capability to retard radionuclide transport.	The evidence indicates that this favorable condition is present at Yucca Mountain: the radionuclide retardation capacity of tuffs is not expected to degrade because of repository conditions.
4. A combination of expected geochemical conditions and a volumetric flow rate of water in the host rock that would allow less than 0.001 percent per year of the total radionuclide inventory in the repository at 1,000 years to be dissolved.	The evidence indicates that this favorable condition is present at Yucca Mountain: expected geochemical conditions and vertical flux of less than 0.001 percent per year of total radionuclide inventory at 1,000 years after permanent closure.
POTENTIALLY ADVERSE CONDITIONS	
1. Ground-water conditions in the host rock that could affect the solubility or the chemical reactivity of the engineered barrier system to the extent that expected repository performance could be compromised.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: the stainless-steel waste-disposal container and waste forms are not expected to show detrimental effects due to host-rock water chemistry.
2. Geochemical processes or conditions that could reduce the sorption of radionuclides or degrade the rock strength.	The evidence indicates that this potentially adverse condition is not presently at Yucca Mountain: sorptive zeolites are metastable, but little reaction is expected in the next 100,000 years. Geochemical processes are too slow to affect repository performance through degradation of rock strength.
3. Pre-waste-emplacement ground-water conditions in the host rock that are chemically oxidizing.	The evidence indicates that this potentially condition is present at Yucca Mountain: water is expected to contain dissolved oxygen and be chemically oxidizing.

the waste. Comparing this amount to the Environmental Protection Agency (EPA) limits provides a means of further categorizing radionuclides into those expected to exceed the EPA limits and those not expected to exceed the limits if completely released by the EBS. Radionuclides expected to exceed the EPA limits (if completely released) then can be grouped by known chemical behavior (e.g., solubility) and ranked for further investigation. This approach by Kerrisk is summarized in Table 2-4. It has been used to bound the resources and time needed for transport studies in the far field. On this basis, the radionuclides of concern (key radionuclides) are ^{59}Ni, ^{99}Tc, ^{135}Cs, ^{234}U, ^{237}Np, ^{239}Pu, and ^{240}Pu, ^{241}Am and ^{243}Am. An analogous approach has been used for radionuclides that are transported as gases. On this basis, only two gaseous radionuclides merit detailed further study: ^{14}C and ^{129}I.

The following sections summarize information obtained through geochemical investigations since the EA and should be read with the overall strategy and approach in mind.

2.3.2.3.2.1 Rock and Mineral Distributions

The understanding of the abundances and distributions of minerals along possible transport pathways has been greatly extended since the EA was published. When the EA was written, the distribution of zeolite minerals was considered the most important factor in determining retardation by sorption; work since then has reinforced the belief in the effective retardation of alkali and alkaline-earth radionuclides by zeolites, but has also established the relative indifference of transuranic radionuclides to zeolite abundance in sorption experiments. However, occurrences of oxide and hydroxide minerals capable of retarding these radionuclides by surface complexation reactions have been confirmed at Yucca Mountain. The knowledge of all mineral distributions has been increased by improved quantitative X-ray diffraction analyses (Bish and Chipera, 1989). The chemical variations within and between zeolitic and nonzeolitic intervals have also been better constrained (Broxton et al., 1986, 1987). Statistical treatment of mineralogic data has revealed the limitations of available data in defining these zeolitic intervals (Campbell, 1987), limitations that can be resolved by further drill-core studies. Similarly, knowledge of the limited stratigraphic variability and general homogeneity of the candidate host rock has been greatly increased through petrologic and statistical analysis (Byers and Moore, 1987). All references cited above expand the understanding of the types of water-rock interactions that can be expected at Yucca Mountain.

Since the EA was written, work has been done to better characterize the mineralogy of fractures (Carlos, 1987; Carlos et al., 1991). This work will be important in evaluating fracture-transport retardation as a component of waste pathways away from the repository. Fracture-associated minerals include the youngest minerals to have formed at Yucca Mountain and the only representatives of Quaternary geochemical alteration at the site (Szabo and Kyser, 1990). Further studies of fracture minerals, particularly calcite, will help to determine the nature and rates of geochemical processes expected to have occurred during the Quaternary Period.

Table 2-4. Important Radionuclides in High-Level Nuclear Waste[a,b]

Radionuclide	Half-life, years	Inventory Percent	Inventory Limit[c]	(Dissolution Rate/ Limit)[d]/year	Probable Sorption Behavior
Ni-59	8.0×10^{4}	0.3	5.2	1.7×10^{-4}	Strong
Zr-93	1.5×10^{6}	0.1	(e)	(e)	
TC-99	2.1×10^{5}	0.7	1.3	1.3×10^{-4}	Weak
Cs-135	3.0×10^{6}	(e)	(e)	3.5×10^{-4}	Strong
U-234	2.4×10^{5}	0.1	2.0×10^{1}	(e)	Weak
Np-237	2.1×10^{6}	0.05	1.0×10^{1}	1.0×10^{-3}	Weak
Pu-238	8.8×10^{1}	0.02	9.7	(e)	Moderate
U-238	4.5×10^{9}	(e)	3.2	(e)	Weak
Pu-239	2.4×10^{4}	17	3.1×10^{3}	6.9×10^{-4}	Moderate
Pu-240	6.6×10^{3}	27	4.8×10^{3}	1.1×10^{-3}	Moderate
Am-241	4.3×10^{2}	51	9.0×10^{3}	4.5×10^{-3}	Moderate
Pu-242	3.8×10^{5}	0.1	1.8×10^{1}	(e)	
Am-243	7.8×10^{3}	0.9	1.6×10^{2}	7.8×10^{-5}	Moderate

[a]Data from Kerrisk (1985).
[b]Based upon pressurized water reactor (PWR) spent fuel 1,000 years after discharge, dissolution by Well J-13-type water, and sorption by Yucca Mountain tuffs.
[c]Radionuclide activity/Environmental Protection Agency (EPA) release limit.
[d]Estimated rate of dissolution of the nuclide in the waste form/EPA release limit.
[e]Unimportant per this ranking criterion.

2.3.2.3.2.2 Ground-Water Chemistry

The chemistry of ground water in both the saturated and vadose zones is important in determining the fate of radionuclides emplaced in a potential repository at Yucca Mountain. Radionuclide solubility is directly related to water composition; because there are different water compositions in the Yucca Mountain vicinity, radionuclide solubility may vary also. Therefore, an accurate analysis of the range and variation of water compositions is required to model radionuclide solubility and transport through time, as well as to design effective radionuclide solubility tests. A ground-water chemistry model is needed to predict dissolution, precipitation, and transport.

Ground water from the saturated zone at Yucca Mountain is a sodium bicarbonate water (Kerrisk, 1987). The pH of saturated zone water falls between 7.0 and 8.2 and appears well buffered by bicarbonate. Measurements of Eh are few but indicate most waters are oxidizing, with reducing waters found at depth in some instances. The nature and character of minerals found in fractures suggests that the most recent alterations of the parent rocks occurred under oxidizing conditions. Minerals indicating alteration under reducing conditions are rare but have been identified. The saturated zone ground-water composition is the result of mineral dissolution, precipitation of secondary minerals (e.g., calcite, clays, and zeolites), and ion exchange. Relevant rock-water interactions have been identified through efforts described above and limit the set of possible composition-determining reactions that need to be included in a ground-water chemistry model.

Yang et al. (1988) extracted water from cores taken from the vadose zone and showed that water in the vadose zone was at higher ionic strength than water from the saturated zone. The higher ionic strength may result from evaporation of water in the rocks, thus increasing the concentration of solutes in the remaining liquid. Precipitation also occurs in this zone, leaving soluble minerals, such as calcite, in fractures and pores. Bicarbonate/CO_2(g) buffers vadose zone water at pH values between 7 and 9. In addition, loss of CO_2 to the gas phase alters ground-water composition. The oxidation of organic matter and mixing of carbonate-rich water from the lower Paleozoic aquifer are processes that also could alter the ground-water composition, but these relationships have not been examined systematically. The range of ground-water compositions used in experiments and modeling is believed to envelope the range expected to be encountered at Yucca Mountain.

2.3.2.3.2.3 Radionuclide Solubility

The solubility of neptunium (Np), plutonium (Pu), and americium (Am) has been measured from oversaturation in water obtained from well J-13. Water from well J-13 is used as the reference water for site studies because unsaturated-zone water is very difficult to extract, and J-13 water is pumped from the potential repository host rock at a location where it is below the water table (Harrar et al., 1990). The solubility of these actinides in this water was measured at three pH values (6, 7, and 8.5) and at three temperatures (25, 60, and 90°C) (Nitsche, 1991; Nitsche et al., 1991). The pH and temperature ranges bracket the expected far-field conditions at the site. In general, these solubility results agree with values cited in the EA (cf. Table 6-26). The Np solubility ranges from a low of ~7 x 10^{-5} M at pH 8.5 and 25°C to a high of ~7 x 10^{-3} M at pH 5.9 and 60°C. For Pu, this range is ~8 x 10^{-9} m at pH 5.9 and 90°C to ~1 x 10^{-6} M at pH 5.9 and 25°C. For Am, the range is ~5 x 10^{-10} m at pH 7 and 90°C to ~3 x 10^{-6} M at pH 6 and 60°C. The americium solubility measured at pH 6 and 60°C is approximately three orders of magnitude higher than the solubility determined at any other pH and/or temperature range investigated and, therefore, may be an artifact. Solubility experiments from oversaturation are also ongoing with these three actinides using water from UE-25p#1 (Nitsche, 1991). This water, collected from the Paleozoic aquifer beneath Yucca Mountain, has a significantly higher carbonate concentration than J-13 water. Preliminary results from the experiments with UE-25p#1 water indicate the solubilities of each of the actinides are comparable to those obtained in J-13 water.

2.3.2.3.2.4 Radionuclide Speciation

Solute speciation may strongly affect the interpretation of experimental results and the representation of retardation processes in models. This knowledge is particularly important for the polyvalent actinide elements. Limited speciation data are available from experiments with Np, Pu, and Am in J-13 water. At 25°C and at pHs of 6, 7, and 8.5, the dominant oxidation states of plutonium have been experimentally determined to be Pu(V) and Pu(VI). Chemical equilibrium calculations using available thermodynamic data predict these oxidation states also, but in proportions almost opposite to what is experimentally observed. Nitsche (1991) recommended that the thermodynamic data base underlying the chemical equilibrium calculations be improved to resolve this discrepancy. Resolution, it is believed, will improve our understanding of other experimental results, but will not alter conclusions drawn from them.

Colloidal actinide species have a propensity to form in the nearly neutral and variable Eh (-200 to 400 mV) waters of the Yucca Mountain region. Size and charge exclusion effects may afford some colloidal species immunity from retardation mechanisms, such as sorption and diffusion, that affect dissolved radioactive species. The chemical and physical nature of colloidal plutonium has been investigated by Newton et al. (1986) and Triay et al. (1991). Light-scattering experiments show that the Pu(IV) colloid can form particles in the size range from 0.002 to 0.03 µm depending on the age and preparation method. This colloid can readily form from dissolved plutonium in other oxidation states by the reducing action of alpha self-irradiation. Its chemical composition is not conclusively established. Nevertheless, several lines of experimental investigation suggest that this colloid is quite similar to crystalline plutonium dioxide. Consistent with this structural supposition, reactivity studies indicate the Pu(IV) colloid is rather inert. It will undergo redox reactions to generate dissolved plutonium in either the trivalent or hexavalent state, but reducing conditions that are much more severe than those encountered naturally at Yucca Mountain are required. Colloidal species will probably be a product of the dissolution of any waste emplaced at Yucca Mountain.

Soluble radionuclide species can also sorb on natural or anthropogenically produced colloidal-sized particles forming a pseudo-colloid, which may then move with the impunity of natural colloids. Particulate concentrations in ground waters of the Yucca Mountain region are believed to be low based upon the results of a few preliminary filtration experiments with samples from pumped wells. The best documented of these experiments measured ~0.3 µg/liter of particulate material in the size range 0.005 µm to 0.4 µm in water from Well J-13. At this concentration, a sorption ratio of ~4 x 10^{8} ml/g would have to be demonstrated for this material to contribute to more than 10 percent of the total waste element flux. Such ratios have been seldom approached in sorption experiments using Yucca Mountain tuffs (Kerrisk, 1987). Repository construction and waste emplacement effects may alter this situation unfavorably, however.

A principal process that may retard the migration of colloidal species is filtration. The efficacy of this process in tuff has been investigated with a colloid surrogate. Spherical particles greater than 1 µm in diameter were mostly filtered and retarded in fractured-tuff column experiments, while 24 percent of particles 1 µm in diameter were eluted (Rundberg et al., 1989). These observations agree with the predicted size dependence of colloid filtration transport models (Tien and Payatakes, 1979). Smaller (i.e., less than 1 µm) neutral particles likely will not be filtered; however, charged particles will be vulnerable to many of the same chemical and electrostatic reactions as ions and charged complexes. Radionuclide transport as colloidal species remains an area of uncertainty.

2.3.2.3.2.5 Radionuclide Sorption

Static batch sorption experiments carried out on whole-rock samples from the lithological units beneath Yucca Mountain have been conducted to investigate the effect of three different variables on sorption coefficients for actinide elements and several fission products. The variables were (1) ground-water composition, (2) water-to-rock ratio, and (3) sorbing element concentration. Sorption coefficients for Ba, Cs, Eu, Ni, Np, Sn, and Sr were measured using different tuff samples and natural ground waters from the Yucca Mountain area (Thomas, 1988). The ground-water composition determines the speciation of the elements in solution. In the batch sorption experiments reported by Thomas (1988) the total concentration of the sorbing element in the solution and the solid phase was determined. This approach to determine sorption coefficients is valid if only one predominant species is present in solution or equilibrium among multiple species in solution is rapid on the time-scale of the experiment. If multiple species are present in solution with different selectivities for the solid phase and interconversion among the chemical species is slow, column experiments will elucidate sorption as a function of chemical species. Even when slow kinetics of speciation exist in solution, batch sorption experiments can provide conservative estimates for sorption coefficients. All species in solution will be eventually converted to the highest sorbing species that was removed from solution by sorption onto a mineral phase along a flow path. Interconversion among species in solution is unlikely to be slow on the time scale that it would take a radionuclide to travel through geologic media (from the proposed repository to the accessible environment). Results from column experiments will be used to obtain distribution coefficients for each species in solution when equilibrium among species in the solution phase is slow. For the alkali and alkaline earth elements, the sorption ratios generally decreased with increasing ionic strength, as would be expected on the basis of mass action considerations. For Eu, the sorption ratio increased with ionic strength. For U and Np, the effect of ground-water composition was less consistent although the sorption ratios for these elements generally increased with ionic strength at constant pH. While ground-water-composition effects upon the actual value of the sorption coefficient were observed in these experiments, sorption remains an important retardation mechanism for all of the radionuclides investigated.

Batch sorption experiments with J-13 water also were summarized by Thomas (1987). Variables investigated in these experiments included mineralogy, temperature, particle size, and testing atmosphere, i.e., oxidizing or reducing. The sorption ratio for Cs, Sr, and Ba (a surrogate for Rd) was proportional to the zeolite content of the tuff. This correlation was less evident for Ce, Eu, and Sn. No correlation with zeolite content was discerned in experiments with Tc, Se, U, and Np; the sorption coefficients for these elements were low on all tuffs. No correlation with zeolite content was observed in experiments with Th, Pu, and Am; sorption coefficients varying from 60 to 1600 ml/g were measured in experiments with these elements. Sorption coefficients for Sr, Cs, Ba, Ce, and Eu increased with increasing temperature to 85°C. Performing the sorption experiments in a reducing atmosphere results in no change or slightly increased sorption for all elements tested except Mn and Sn. Sorption coefficients increased by factors of 2 to 5 when the tuff material particle size was reduced to less than ~38 µm.

The experiments on the effects of water-to-rock ratios on sorption coefficients were designed to test whether these effects could be modeled with isotherm equations. Earlier data on a zeolitic sample suggested this may not be true (Wolfsberg et al., 1982). New experiments on a zeolitic tuff used a superior filtration technique to separate the solution phase from the solid phase. Results from these experiments (LANL, 1991) support the use of isotherm equations in modeling the effect of variations in water-to-rock ratios on sorption coefficients.

Additional experiments were done to investigate Am sorption onto devitrified tuff in J-13 water (Triay et al., 1991c). The purpose of these experiments was to determine whether earlier Am sorption experiments may have been oversaturated with an Am-bearing phase. The concentration of Am in the feed solution for these experiments was well below the best estimate of the solubility of Am in J-13 water. Special techniques involving mass-spectrometric isotope dilution analysis were used to analyze the very small concentration of Am left in solution after sorption on the tuff sample had reached steady-state. The main conclusion of this work is that earlier experiments resulted in conservative estimates of the Am sorption coefficients on tuff. That is, the sorption coefficients measured in the new experiments were equal to or larger than the values measured previously.

Several types of batch sorption experiments were carried out on pure mineral separates to identify which mineral phases present in tuffs at Yucca Mountain were most effective in sorption of each key radionuclide and to investigate the details of the sorption reactions for the most important radionuclide/mineral pairs. The sorption of anionic species of Tc (TcO^{-}_{4}) and Np ($NpO_2CO^{-}_{3}$) in J-13 water was studied on oxides, carbonates, clays, and zeolites. Of the phases studied, only the iron oxides, goethite, and hematite had any affinity for Tc and then only a small affinity. Iron and manganese oxides had large affinities for Np, while clays, zeolites, and carbonates had relatively small affinities for Np (Meijer et al., 1989). These results for iron and manganese oxides corroborate earlier findings regarding the adsorption of actinides by iron and manganese oxyhydroxides (Means et al., 1978). The Np complex sorbed to the goethite surface was investigated with the Extended X-ray Absorption Fine-Structure (EXAFS) technique (Combes et al., 1990), and the results of this investigation were used to develop a surface complexation model to explain retardation of the nuclide on goethite (Kohler et al., 1990). Evidence is accumulating that anionic species of key radionuclides released by the engineered-barrier system are retarded somewhat by minerals other than zeolites present along potential flow paths.

Clinoptilolite-rich formations at Yucca Mountain are expected to play an important role in retarding radionuclides that may be released from the potential repository, and a considerable amount of chemical modeling has been done to investigate the sorptive potential of clinoptilolite (Bruton and Viani, 1990). Results show that sorptive potential is sensitive to clinoptilolite composition and abundance and to ionic strength of the pore fluids.

Static batch-sorption studies have been augmented with dynamic experiments using crushed tuff (Treher and Raybold, 1982; Rundberg et al., 1989) and pure mineral separates (Triay et al., 1991c) in saturated columns. Validating the sorption results obtained by batch techniques is important to decisions about the applicability of batch results to the actual situation in the field. Crushed-tuff column results for alkali and alkaline earth elements agree with batch results: a rapid ion-exchange mechanism explains sorption of these elements. Crushed-tuff column experiments with Tc suggest that steric hindrance caused by the pertechnetate ions being larger than the aperture size of porous tuffaceous rock and repulsion of these ions by the negatively charged mineral surfaces preclude sorption of this radionuclide.

This effect is described as anion exclusion and actually may result in a mean solute travel time that is less than the mean solvent travel time. Actinide transport in crushed-tuff columns (Thompson, 1989) cannot be explained by isotherms fitted with batch sorption coefficients; a small fraction of the actinides is eluted with a sorption coefficient smaller than the one calculated from batch experiments. Triay et al. (1991c) reached a preliminary conclusion that the rate of the actinide speciation reaction(s) or kinetics in the reference J-13 water is slow. If confirmed, this conclusion means that batch sorption coefficient measurements for these elements provide conservative estimates of this parameter for use in transport calculations, assuming matrix flow and transport. Multiple actinide species present in a solution will be converted to the highest sorbing species as sorption proceeds. The long times believed to characterize ground-water flow at Yucca Mountain will enable these reactions to proceed to reasonable degrees of completion. Therefore, retardation will occur as a result of sorption with a coefficient of at least the magnitude determined by batch experiments.

Experiments with solid tuff in saturated columns also affirm the sorption findings obtained in batch experiments with alkali and alkaline earth elements, provided the detailed hydrologic characteristics of the column are known (Rundberg et al., 1991).

Experimental results for fractured-tuff columns agreed with transport model calculations for conservative (nonsorbing) tracers (Rundberg et al., 1989; Rundberg et al., 1982). The transport model for this calculation assumed vertical flow in the fractures and horizontal diffusion into the matrix perpendicular to the fracture (Neretnieks, 1980). A small fraction of sorbing tracers traveled the fracture column length seemingly unretarded. Hydrologic channeling or dispersion may explain this result.

Microorganisms also may affect the transport of actinide elements in one or more of the following ways by

1. Altering the composition of the ground-water chemistry through changes in pH or Eh and production of metabolites, such as CO_2, H_2S, NH_3, and NO_3

2. Producing chelating agents that can solubilize radioactive elements

3. Transporting radioactive elements via biological movement

4. Affecting the colloidal transport of radioactive elements

5. Sorption of the radioactive elements onto a nonmotile solid phase, thereby retarding the transport of the radionuclide

6. Plugging pores in the host matrix, thereby retarding the movement of ground water.

Batch sorption experiments (Hersman, 1986) have demonstrated that bacteria were able to remove actinide elements from solution. In these experiments, the bacteria, on a per-gram dry-weight basis, sorbed Pu(IV) nearly 10,000 times greater than crushed tuff. It is possible that microorganisms may strongly sorb significant quantities of the actinide elements and transport these elements via microbial motility. In fact, early studies demonstrated that microorganisms were able to penetrate 4.0 mm-thick wafers of tuffaceous rock from the Calico Hills unit.

Hersman (1988) demonstrated that in the presence of microorganisms, the formation of colloidal agglomerates was significantly accelerated. This may be an important observation regarding radionuclide transport by colloidal particles. Agglomerated particles more readily settle out of suspension or become entrapped in small pore openings in the rock matrix. It is therefore entirely possible that, in the presence of microorganisms, transport by colloidal particles would be retarded by these processes.

Microorganisms can strongly influence the movement of metals through soils. One mechanism is the microbial production of powerful chelating agents, called siderophores, that may solubilize otherwise very insoluble cations, e.g., Fe(III). In the last three decades, over 80 siderophores have been isolated and characterized and binding constants have been reported to be as high as 10^{52} (Neilands, 1974). Neilands (1981) believes that because Fe(III) and Pu(IV) are similar in their charge/ionic-radius (4.6 and 4.2, respectively), Pu(VI) may possibly serve as an analog to Fe(III) and could therefore be solubilized by siderophores. Experimental results demonstrate that a siderophore produced by a soil microorganism isolated from Yucca Mountain form complexes with Pu(IV). It is possible that actinide elements could be transported in the environment via the siderophore transport system.

Work continues on the development of a biological transport term, but evidence does not suggest that such a term would alter the current view of geochemical characteristics and processes in the Yucca Mountain region.

Data reviews and concept development work has lead to several new products. Meijer (1990) reviewed the methods used to obtain sorption coefficient data and the data obtained up to 1988. He also discussed data needs in terms of requirements set forth by the Nuclear Regulatory Commission in its Technical Position on Sorption and other regulatory concerns. Concept development activities have concentrated on the formulation of a "sorption strategy" (LANL, 1991). This strategy provides a defensible approach for the incorporation of the sorption barrier into performance assessment calculations.

2.3.2.3.2.6 Mineral Alteration and Stability

The knowledge of mineral stability has been greatly advanced by examining the past hydrothermal alteration of tuffs at Yucca Mountain, thereby using the site itself as a "natural analog" for thermal-pulse alteration (Bish, 1989; Levy and O'Neil, 1989). Localized repository-induced alteration of the lower vitrophyre in the Topopah Spring Member is probable (Levy and O'Neil, 1989). The mineralogic data suggest that the vitrophyre, thus altered, may have equal or increased capability to retard radionuclide transport. These studies have strengthened earlier assumptions that temperatures of around 100°C mark a critical boundary above which mineral transformations are accelerated. Steam generation in the unsaturated zone near the emplaced waste has also been hypothesized as a potential cause of irreversible clay-mineral collapse with a negative impact on sorption potential (Bish, 1988a). This hypothesis will be tested by experimental work in progress (Bish, 1988a,b) to provide temperature limits within which the mineral assemblages extant and predicted to occur along transport pathways would remain unaltered or alter to assemblages of equal or greater retardation potential. These limits then can be assessed in terms of the thermal aureole around the potential repository.

2.3.2.3.3 Current Status of Geochemistry Technical Issues

- Technical Issue 1: Are all expected radionuclide species retarded by the geochemical characteristics of and processes operating in the far field?

  Improved knowledge of mineral abundances and distribution, particularly in fractures, strengthens the case for effective sorption of the radionuclides of concern at Yucca Mountain. The effectiveness is least for anionic species of Tc and Np. In general, known and expected geochemical characteristics and processes are expected to retard the rate of transport of radionuclides released to this setting relative to ground-water travel.

- Technical Issue 2: Will anionic and colloidal radionuclide species occur in the far field? Will the migration of any anionic and colloidal species be retarded by the extant and expected geochemical characteristics and processes in the far field?

  Although size and charge exclusion processes may adversely affect the transport of some radionuclides, there is little experimental evidence that these processes are effective within the geologic setting of Yucca Mountain. Filtration appears to be an effective process for retarding colloidal species.

- Technical Issue 3: Will the extant and expected geochemical characteristics and processes retard gaseous radionuclide migration?

  Problems related to this issue are discussed in Postclosure Rock Characteristics (Section 2.3.3) and in the Postclosure System Guideline (Section 2.4).

2.3.2.4 Conclusions and Recommendations for Future Geochemistry Activities

The consensus of the Core Team is that available evidence continues to support the lower-level suitability finding for the qualifying condition. Present and expected geochemical characteristics of the Yucca Mountain site are judged compatible with waste containment and isolation. Further, on the basis of the evaluation presented in Section 2.3.3, reasonably available technology is more than adequate to design the EBS in such a way as to mitigate any potentially adverse geochemical characteristics or processes at the Yucca Mountain site. Uncertainties remain with regard to the retardation that is expected for specific radionuclides and, therefore, the higher-level finding is not supported at this time.

As part of the ongoing site characterization program, the following actions should reduce uncertainties with regard to the geochemistry qualifying condition:

1. Complete ongoing studies to resolve, to an adequate degree, the remaining uncertainty regarding speciation, retardation factors, and mechanisms affecting anionic and colloidal radionuclide species. (See the SCP (DOE, 1988a) Section 8.3.1.3).

2. Demonstrate total postclosure system performance, taking into account the present and expected geochemical characteristics of the site, at or better than the limits, (i.e., cumulative release, annual dose equivalent, concentrations in ground water, time of complete containment, and rate of release from the EBS), specified in the Postclosure System Guideline using acceptable integrated-system models. To ensure the adequate and accurate treatment of present and expected geochemical characteristics and processes in

these models, subsystem and detailed models of these characteristics and processes should be developed and accepted as plausible by the informed scientific community.

3. Activate tasks to understand gaseous radionuclide flow and transport in porous, fractured media from high-level radioactive waste emplaced in unsaturated geologic media. This work may require expansion of previously defined site characterization activities (e.g., Study Plan 8.3.1.3.8.1, Gaseous Radionuclide Transport Calculations and Measurements).

2.3.3 ROCK CHARACTERISTICS TECHNICAL GUIDELINE

2.3.3.1 Statement and Discussion of Qualifying and Disqualifying Condition

Qualifying Condition [10 CFR 960.4-2-3(a)]: "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 10 CFR 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."

Discussion. Certain characteristics of the potential host rock are important to the long-term isolation capability of a geologic repository. Confidence is needed that mining operations during repository construction and the heat generated by the emplaced wastes will not cause deleterious fractures or thermal alteration in the host rock that could significantly diminish the ability of the site to contain and isolate 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 degraded.

All Postclosure Technical Guidelines require compliance with the requirements specified in the Postclosure System Guideline (See Section 2.4). In addition, the qualifying condition for Postclosure Rock Characteristics specifies compliance with the requirements in 10 CFR 60.113 for limiting radionuclide releases from the engineered barrier system (EBS) using reasonably available technology (RAT).

Besides the qualifying condition, this guideline consists of two favorable conditions and three potentially adverse conditions. These conditions and the corresponding findings, reported in the Environmental Assessment (EA) for Yucca Mountain (DOE, 1986), are summarized in Table 2-5. These findings and the evidence available at the time of the Environmental Assessment are discussed in Section 2.3.3.3.1.

2.3.3.2 Approach for Postclosure Rock Characteristics Evaluation

2.3.3.2.1 Identification and Basis for Postclosure Rock Characteristics Technical Issues

The technical guideline evaluation involves, as a first step, the identification of issues related to postclosure rock characteristics at the Yucca Mountain site. The issues of interest are based principally on the interpretation of the qualifying condition for the guideline. Also important are the results of the previous Environmental Assessment (EA) and pertinent work since the EA that addresses these issues.

Table 2-5. Summary of Environmental Assessment Findings for Postclosure Rock Characteristics (DOE, 1986)

CONDITION	DOE FINDING
FAVORABLE CONDITIONS	
1. A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration and location of the underground facility to ensure isolation.	The evidence indicates that this favorable condition is not present at Yucca Mountain: the host rock is sufficiently thick and laterally extensive to ensure isolation; however, significant lateral flexibility cannot be claimed until site-characterization data are available.
2. A host rock with a high thermal conductivity, a low coefficient of thermal expansion or sufficient ductility to seal fractures induced by repository construction, operation, or closure or by interactions among the waste, host rock, ground water, and engineered components.	The evidence indicates that this favorable condition is present at Yucca Mountain: the host rock possesses a low thermal expansion coefficient; calculated thermal and mechanical behavior of the host rock suggests no adverse response to be expected.
POTENTIALLY ADVERSE CONDITIONS	
1. Rock conditions that could require engineering measures beyond reasonably available technology for the construction, operation, and closure of the repository, if such measures are necessary to ensure waste containment or isolation.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: no rock conditions identified to date are expected to require extraordinary engineering measures to ensure waste containment or isolation.
2. Potential for such phenomena as thermally induced fractures, the hydration or dehydration of mineral components, brine migration or other physical, chemical or radiation-related phenomena that could be expected to affect waste containment or isolation.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: the potential host rock is expected to be physically and chemically stable; calculations indicate that thermally induced fracturing would be minor and would not be expected to affect waste containment or isolation.

Table 2-5. Summary of Environmental Assessment Findings for Postclosure Rock Characteristics (DOE, 1986) (continued)

CONDITION	DOE FINDING
POTENTIALLY ADVERSE CONDITIONS (continued)	
3. A combination of geologic structure, geochemical and thermal properties, and hydrologic conditions in the host rock and surrounding units such that the heat generated by the waste could significantly decrease the isolation provided by the host rock as compared with the pre-waste-conditions.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: no combination of host-rock properties and conditions has been identified that would be expected to cause a decrease in isolation capability because of the heat load.
QUALIFYING CONDITION	
The present and expected characteristics of the 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 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 set forth in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.	Existing information does not support the finding the site is not likely to meet the qualifying condition (Level 3): the characteristics of the host rock and surrounding units are expected to permit compliance with containment or isolation requirements. Available data suggest rock characteristics are not expected to compromise performance of the waste package.

The postclosure rock characteristics issues were identified based on a careful review of this guideline condition, information presented in the EA, and a current understanding of the status and plans for associated testing activities. The scope of this guideline is encompassed by the following three issues:

- Technical Issue 1: Thermomechanical Alteration

  Will repository-induced thermomechanical alteration of the host rock characteristics over time at Yucca Mountain permit compliance with the requirements specified for radionuclide release, given the EBS and RAT?

- Technical Issue 2: Hydrologic and/or Geochemical Alteration

  Will repository-induced hydrologic and/or geochemical alteration of host-rock characteristics over time at Yucca Mountain permit compliance with the requirements specified for radionuclide release, given the EBS and RAT?

- Technical Issue 3: Radiation-Induced Alteration

  Will the alteration of the characteristics of the host rock over time due to radiation in the repository permit compliance with the requirements specified for radionuclide release, given the EBS and RAT?

In addition to these issues, the proposed host rock must be of sufficient thickness and lateral extent to permit isolation consistent with the Postclosure System Guideline. The Preclosure Rock Characteristics Guideline explicitly requires that the thickness and lateral extent and the characteristics and composition of the host rock be suitable for accommodation of the underground facility. This issue is addressed in the evaluation of the Preclosure Rock Characteristics Guideline (See Section 3.3.3.2). Failure to resolve this preclosure issue with a higher-level suitability finding would render any postclosure considerations moot.

2.3.3.2.2 Information or Actions to Resolve Postclosure Rock Characteristics Issues

Resolution of Technical Issue 1: Thermomechanical Alteration

This issue can be resolved if the host rock for the potential repository can be determined to have thermomechanical properties compatible with long-term isolation of the waste given the EBS and RAT. Results from laboratory experiments (Price et al., 1987; Price, 1986; Nimick et al., 1987; Nimick, 1990a, b), field experiments (Zimmerman, 1986a, and Buscheck et al., 1991b), and numerical analyses (Bauer and Costin, 1990; Ehgartner and Kalinski, 1988) indicate that thermomechanical properties are such that long-term isolation will be feasible using RAT. Resolution of this issue is expected to be gained through a series of full-scale heater tests, scheduled to be performed in the Exploratory Studies Facility.

Resolution of Technical Issue 2: Hydrologic and/or Geochemical Alteration

This issue can be resolved if the host rock for the repository can be determined to have hydrologic and geochemical characteristics compatible with long-term isolation of the waste given the EBS and RAT. Results from laboratory (Lin and Daily, 1991; Knauss, 1987), field (Buscheck et al., 1991c), and modeling studies (Nitao, 1988; Knauss and Wolery, 1988) indicate that the hydrologic and geochemical characteristics of the potential host rock are such that long-term isolation will be feasible using RAT. This issue is expected to be resolved through a series of full-scale heater tests to be performed in the Exploratory Studies Facility. These tests should be based on reasonably mature designs for both geometry of repository openings and the waste stream.

Resolution of Technical Issue 3: Radiation-Induced Alteration

This issue can be resolved if it can be shown that either (1) radiation exposure has a negligible effect on rock characteristics important to repository performance or (2) changes in rock characteristics caused by radiation exposure can be accommodated using RAT. Work by Durham et al. (1986) indicates that radiation has negligible effect on mechanical properties of granitic rocks, and a similar result is expected for tuff although the work has not yet been done. Geochemical studies indicate that radiolysis in the tuff-air-water-waste environment may lead to formation of various compounds that do not occur naturally in the host rock and that change the pH. While this area requires more study, the impact of such changes on the geochemistry of the system is expected to be minor.

2.3.3.3 Status of Current Postclosure Rock Characteristics Information

2.3.3.3.1 Summary of Environmental Assessment Findings for Postclosure Rock Characteristics

The EA evaluation for this guideline summarized available relevant data, including geologic, mineralogic, physical, thermal, and mechanical attributes of relevant rock types, for analyzing the impact of rock characteristics on waste containment and isolation. It also presented the assumptions, limitations, and uncertainties associated with both the available data and models. Each of the favorable and potentially adverse conditions was addressed (See Table 2-5) and on the basis of these evaluations, a lower-level (Level 3) finding was made with respect to the postclosure rock characteristics qualifying condition.

A major discussion within this guideline involves assessing the thickness and lateral extent of the potential repository horizon. The EA concluded that the potential host rock within the primary repository area at Yucca Mountain is sufficiently thick to provide significant vertical flexibility in the placement of the repository to ensure waste isolation.

The EA evaluation of thermal conductivity and thermal expansion of the potential host rock identifies two key points that relate to the discussion of these properties at the Yucca Mountain site. First, the site is in the unsaturated zone; and second, the Topopah Spring Member is highly fractured. Given these characteristics, the values reported for thermal conductivity and thermal expansion support a conclusion that the potential host rock will accommodate the induced thermal and mechanical stresses developed by the emplacement of waste with no adverse effect on containment or isolation.

The evaluation of rock conditions with respect to the need for use of engineering measures that are beyond RAT concludes that no such conditions have been identified and that existing technology is adequate to construct, operate, and close the repository consistent with the objectives of waste containment and isolation. This conclusion was based upon both (1) the evaluation of technology required to deal with rock conditions during the preclosure phase and (2) the consideration of postclosure rock characteristics, including the chemical environment, mechanical behavior, hydraulic conductivity, and shaft and borehole sealing.

The EA evaluation of the potential for thermally induced fracturing, mineral degradation, or other phenomena that could be expected to affect containment or isolation concluded that these effects are not likely to be significant. The EA stated that the host-rock mass is highly fractured, and any additional thermally induced fracturing would be minor. That evaluation pointed out that more than 98 percent of the rock is composed of nonhydrous minerals that would not be subject to significant dehydration effects. Dehydration of the low abundance (<2 percent) zeolites and clays beyond a distance of about 23 m from the repository horizon was judged to be unlikely; furthermore, the major zeolitized rock units are at least 100 m below the repository midplane. In addition, evidence is cited that even if such reactions were to occur, they would probably be reversible at temperatures below 200°C and would not affect waste isolation.

The final potentially adverse condition addresses combinations of geologic, geochemical, and thermal properties such that waste-decay heat could significantly decrease the isolation provided by the host rock. Thermal effects on radionuclide retardation, rock permeability, and convective transport of radionuclide-bearing ground water are evaluated. The EA concluded that while the waste-decay heat has a potential for influencing each of these processes, none of the effects are expected to significantly affect the host-rock isolation capability.

2.3.3.3.2 Review of Postclosure Rock Characteristics Information Acquired since the Environmental Assessment

The EA cites information available before 1986. Since that date, substantial information has been gathered on the rock characteristics at Yucca Mountain. Work has also been done at analog sites excavated in other tuff units thought to be similar to the potential unit at Yucca Mountain. In general, the work done since the EA supports the findings of the EA.

Intrinsic host rock properties appear to permit compliance with both the Postclosure System Guideline (Section 2.4) and the EBS radionuclide release limits (10 CFR 60.113) using RAT.

One possible exception, identified since the analyses presented in the EA, involves the possibility of rapid releases of the radionuclide C-14 as gaseous carbon dioxide. Following a breach of engineered barriers, the gaseous carbon dioxide could be transported to the accessible environment by convective or diffusive mechanisms. Sufficient quantities of C-14 are available from spent fuel cladding to approach the Environmental Protection Agency (EPA) limits for release of this isotope. Van Konynenburg (1991) has reviewed the available information on the potential for this release and concludes that this gaseous compound may be rapidly transported through the unsaturated zone.

The rock characteristic that permits this rapid transport is nonliquid, filled fractures in the host rock that are expected to intercept waste emplacement openings. Connections, if present, between these host-rock fractures and similar fractures in the overlying units, extending to the surface, provide continuous pathways for release of gaseous radionuclides to the accessible environment. In addition, thermal energy released by waste decay provides a driving mechanism for this process. System performance implications for this potential release mechanism are discussed in the Postclosure System Guideline (Section 2.4.2).

<u>Thermomechanical Properties of Host Rock</u>

The physical, mechanical, and thermal properties of rock from the potential repository horizon have been investigated since the EA via a series of laboratory experiments. Benchmarking exercises for verification of several thermal and mechanical codes have also been performed (Bauer and Costin, 1990). Schwartz (1990) presents an extensive data base for two important physical properties (i.e., density and porosity) for tuffs from the unsaturated zone at Yucca Mountain. The mechanical data (Price et al., 1987) indicate that the intact rock is quite strong, with a uniaxial strength of approximately 160 MPa and a high deformation modulus. Uncracked samples have stress-strain curves that show nearly linearly elastic behavior up until failure. Samples with cracks exhibit nonlinear stress-strain behavior as expected when stress is above 50 percent of the failure stress. Most of this work is reported in the Reference Information Base (DOE, 1987b, 1991f).

Most tests for compressive strength have been conducted on samples that were saturated with water and tested under drained conditions. Rocks are generally weaker when saturated with water. Olsson and Jones (1980) show that for Grouse Canyon Tuff, a volcanic rock unit located at the Nevada Test Site (NTS), saturated samples are approximately 24 percent weaker than dry samples in unconfined compression. The thermomechanical properties of Grouse Canyon Tuff are very similar to rock in the potential repository horizon.

The effect of sample size on mechanical properties has been examined for samples of the potential repository host rock, the Topopah Spring Member of the Paintbrush Tuff, by Price (1986). That study found both ultimate strength and axial strain at failure were inversely related to sample diameter, while Young's modulus and Poisson's ratio were independent of sample diameter.

Olsson (1987, 1988) has investigated joint properties of rock from the potential repository horizon. He found that the strength of a joint may increase with time of stationary contact and that joint properties depend on stress history. He indicated, however, that this latter area needs more investigation. To date, data on the effect of environmental variables (such as temperature and moisture content) and stress history on joint properties are not available. (Note: Complete in situ tests are not possible. Some parameters are calculated and then used as values for controlled experimental variables.)

The effect of temperature on strength for rock in the potential repository horizon is not well defined at this time. Rock strength generally decreases with increasing temperature, and Price et al. (1987) report that, for samples from the potential repository horizon, Young's modulus shows an average decrease of 16 percent as temperature is raised from 22° to 150°C at both 0 and 5 MPa confining pressures.

Nimick (1990a, b) has reported revised values of thermal properties, and these more recent values show thermal conductivity to be somewhat higher than reported in the EA, with in situ thermal conductivity for both dry and saturated conditions about 2.1 W/m °C. Recent values for thermal expansion are somewhat lower than previously thought, and values are defined over specific ranges in temperature. Thermal capacitance has been measured and equations developed to describe thermal capacitance over a series of temperature ranges (Nimick, 1990a).

Several analyses have been completed to assess the stability of underground excavations at Yucca Mountain. A synopsis of these studies is presented by Ehgartner and Kalinski (1988). They report that all analyses indicate that the shafts and drifts can be constructed and will remain stable with a minimum of ground support through decommissioning of the repository. Thus, results of more recent analyses are consistent with the conclusions of the EA. Note that most of the numerical studies to date have (a) been limited to two-dimensional analysis and (b) incorporated fracture geometries and fracture properties that are highly idealized. While benchmarking for verification of many of these codes is underway, the codes must also be validated before they are used to evaluate performance.

In addition, Arulmoli and St. John (1987), Christianson and Brady (1989), and Bauer and Costin (1990) have estimated temperature, stress, and deformation fields around emplacement holes in the potential repository. These studies all found that spalling due to thermal stresses and fractures or slip along fractures would be minor and that thermally induced fractures or displacements would not threaten containment or isolation performance at Yucca Mountain.

A series of field experiments have been performed in Grouse Canyon Tuff at G-Tunnel on the Nevada Test Site (NTS) in conjunction with an extensive series of analyses aimed at obtaining a better understanding of the rock-mass response to thermal and mechanical loads. The experiments include two small-diameter heater experiments, a heated-block experiment, a mine-by experiment, flatjack/slot deformation experiments, and in situ stress measurements. These experiments and supporting analyses are summarized by Bauer et al. (1988). While models for the effect of joints have been developed, joints were not considered in these analyses. Studies indicate that stresses are within the elastic range.

Hydrologic and Geochemical Characteristics

Much has been learned since the EA about the thermohydrological effects that are anticipated from the dissipation of radioactive decay heat in the unsaturated fractured host rock. Numerical models have predicted the time-dependent temperature distribution within the host rock and surrounding hydrostratigraphic units for various repository design concepts, thermal loading densities, and waste receipt and operating scenarios (Ryder, 1991; Ballou et al., 1990). Most of these models involve spatial and temporal superposition of heat conduction calculations to account for the emplacement of individual heat sources over the operational life of the repository and the radioactive decay. Areal power densities (APDs) ranging from less than 20 to greater than 100 kW/acre and average waste ages from 10 to 90 years have been modeled. These models not not account for fluid phase changes or heat-transfer mechanisms other than heat conduction.

A field experiment to investigate the physical processes that should be incorporated into models describing thermohydrologic and geochemical processes in fractured, porous, densely welded tuff was conducted at G-Tunnel on the Nevada Test Site (Buscheck et al., 1991b). The experiment used a heater placed in a horizontal orientation, and results show that the predominant heat flow mechanism was heat conduction (Buscheck and Nitao, 1991b). Fractures appeared to serve as the predominant flow paths for gases and liquids, and fracture permeability to air increased somewhat due to the heating cooling cycle. This experiment did not show any mechanisms or phenomena that would indicate that tuffaceous rock is unsuitable for siting of the repository.

Hydrothermal model calculations have been performed for a wide range of fracture and matrix properties in the unsaturated zone using simplified repository geometries. These models include boiling and condensation effects, convection of latent and sensible heat, and thermal radiation. In general, these models predict a drying-out of the near-field rock by boiling the vadose water in the rock matrix and flow of water vapor through fractures to cooler regions where it condenses. Because of the very low matrix permeability of the host rock, this condensate will drain considerable distances along fractures before it is totally imbibed by the matrix. The combination of vapor flow away from the heat source and gravity-driven condensate flow down fractures tends to promote shedding of condensate off the sides and away from the boiling zone. This condensate shedding effect was observed during the G-Tunnel heater experiment (Buscheck, et al., 1991b; Buscheck and Nitao, 1991b).

Recent hydrothermal model calculations over a range of fuel ages and APDs have shown the potential for significant boiling and rock dry-out benefits for high APDs (i.e., APD > 80 kW/acre) (Buscheck, 1991). For 60 year old pressurized water reactor (PWR) fuel and an APD of 114 kW/acre, these calculations show near-field temperatures remaining above boiling for 5,000 to 10,000 year, with the re-wetting of the dry-out zone to ambient saturation requiring 100,000 to 200,000 years. The probability of fracture flow reaching a waste package is greatly reduced by near-field boiling conditions. While the dry-out zone is re-wetting to ambient saturation, matrix flow will be directed back toward the repository. Buscheck (1991) found that much of the re-wetting of the dry-out zone occurs from below the repository horizon. The resulting upward matrix flux below the repository will retard matrix-dominated radionuclide transport toward the water table.

For a range in expected repository fracture and matrix properties, hydrothermal calculations of the repository show the predominant heat flow mechanism to be heat conduction (Buscheck, 1991). The volume of rock dry-out and the duration of near-field boiling conditions was found to primarily depend on (1) the thermal properties of the unsaturated zone and (2) thermal loading conditions. Moreover, mass flux rates generated by condensate draining for high APDs are much greater than current estimates of flux. The modeling study by Buscheck (1991) showed the duration of near-field dry-steam boiling conditions is insensitive to a wide range in infiltration flux and initial saturation distribution.

Buscheck (1991) found that even for APDs as low as 20 kW/acre, the flow of water vapor and condensate driven by the heat of radioactive decay may dominate the ambient hydrological system. Elevated temperatures and condensate drainage have the potential of driving geochemical changes that may significantly alter the flow and transport properties of the natural barriers underlying the repository horizon. Key concerns include whether zeolitization of the vitric nonwelded Calico Hills unit may significantly reduce its capacity to retard fracture-dominated flow. Because of the potential for substantial boiling and rock dry-out benefits at high APDs, the impact of these uncertainties may be significantly reduced.

Geochemical simulations using the geochemical computer code, EQ 3/6, have evaluated the effect of variations in the chemistry of fluids on subsequent fluid-rock interaction. Preliminary calculations suggest that the initial Eh and pH of pore waters do not significantly affect subsequent fluid-rock interactions at elevated temperatures, especially at high rock-to-fluid ratios and over extended time periods. The rates of dissolution and precipitation of several mineral phases that occur in the potential repository horizon have been determined over a wide range of temperature and pH conditions (Knauss and Wolery, 1988).

A preliminary investigation of the influence of phase transition from alpha-to-beta-cristobalite on cristobalite properties was undertaken to determine if the dissolution of cristobalite would be affected by structural change. Preliminary results indicate that an amorphous phase may form during the transition and may persist over a temperature interval of several tens of degrees if water vapor is present (Meike and Glassley, 1989). Overall, geochemical simulations of fluid-rock interactions suggest that elevated temperature will favor the stability of minerals that are already abundant at Yucca Mountain.

The addition of man-made materials to the near-field environment may modify the chemical environment and influence geochemical reactions that may occur. A broad spectrum of materials may be introduced into the waste repository during construction and operation. An inventory of the man-made materials introduced into the Exploratory Studies Facility (West, 1988), which can serve as a prototype for material usage at the proposed repository, indicates that more than 260 different items of man-made materials could be introduced into the vicinity of the waste package emplacement boreholes. Some materials, such as metals, bonding agents, and concrete, will serve as functional parts of the EBS design. Passive materials will be introduced to serve a number of other operational purposes, and passive materials will also be present as waste. The introduced material will be present in gas, liquid, and solid phases; as inorganic and organic compounds; and in various reactive states.

Some materials, such as concrete, may be present in large quantities and could be of particular concern. Cement is predominantly composed of calcium-bearing phases that crystallize when water is added to a mixture of calcium oxide, silicates, and other phases. Disintegration and dissolution of cementitious materials may increase the pH of water. Examinations of ground waters that issue from rocks containing cement-type minerals and from ancient concretes have been used to gain insight into the long-term performance of cements. Water with a pH as high as 12.5 has been collected from rocks containing portlandite, ettringite, tobermorite, and higher-temperature minerals (Khoury, 1985; Neal and Stanger, 1984). A preliminary calculation of phases in equilibrium with water (Barnes and Roy, 1983) is consistent with these natural data. Ancient Roman concretes often incorporated pyroclastics, including acidic tuffaceous material that may be applicable to modern portland cements in that similar aggregate is being considered for use in the repository. Examination of these ancient materials demonstrates that low permeability cements, and particularly pozzolanic cements, have the greatest durability (Roy and Langton, 1983; 1986).

Hydrocarbons that result from the thermal decomposition of greases, paints, and other organic items can form ligands that may enhance radionuclide transport. The limited data that exist on this subject suggest that organic compounds are more effective at forming complexes with radionuclides than are inorganic compounds or single ions (Raloff, 1990). The presence of colloidal and organic products may thus produce an environment that enhances radionuclide migration. As a result, the movement of radionuclides may not be predictable on the basis of inorganic chemistry alone. The number and significance of other materials to be used in the repository that fall into this category are still unknown and will be dependent on design and construction technique considerations.

Colloids exist naturally, as fracture lining materials, clays, bacteria, algae, and humic acid, but can also be the product of degradation of man-made materials and debris, such as glass, fuels and greases, metals, and organic waste. A number of processes have already been identified as potential originators of radionuclide-sorbing colloids in the waste package environment (Olofsson et al., 1981; 1982a, b). These sources include

1. Leaching of the waste form by ground water
2. Corrosion of canister or container material
3. Degradation of backfill material (if present)
4. Naturally occurring colloids, such as clays, organics, and precipitates
5. Organic materials that result from man-made modification of the near-field environment.

Effect of Radiation

Since the EA, investigations of the effect of radiation on postclosure rock characteristics have examined the effect of radiation on rock strength and the geochemical effects of radiolysis in a tuff-air-water-waste-form system. To study the effects of radiation on mechanical strength, Durham et al. (1986) conducted a series of unconfined compression tests on cylinders of quartz monzonite, half of which had been irradiated with gamma radiation and half of which had not. A similar series of tests was conducted on samples of Westerly granite. These experiments showed no statistically significant change in unconfined compressive strength for either rock type. Null results were also found for the effect of gamma irradiation upon Young's modulus and Poisson's ratio. They concluded that gamma irradiation has no effect on the strengths of either rock type.

A literature review (Reed and Van Konynenburg, 1987) documented that in dry air systems, nitrogen dioxide and nitrous oxide are the most abundant radiolysis products, although minor amounts of ozone, nitric oxide, and nitrogen pentoxide may also be produced. In the presence of water as liquid or vapor, nitric acid forms instead of nitrogen dioxide; nitrous oxide forms in smaller quantities than in dry air systems. The amount of nitric acid that forms is a function of the amount of water present, the initial nitrogen/oxygen ratios, and the composition of the vessel in which the experiments were performed. The presence of man-made materials in the vicinity of waste packages, as well as the waste package itself, may therefore, be important parameters for determining the radiolysis products in the near-field environment. The formation of ammonia is restricted to nitrogen-water systems and to systems in which the ratio of hydrogen to oxygen is high. Because of these limitations, ammonia is not expected to be a significant radiolysis product in the waste package environment.

Measurable changes in solution pH occur when radiation interacts with glass waste forms, tuff, air, and water at 90°C (Bates et al., 1988). From these experiments, it is evident that solution pH remains near neutral to slightly acid (pH values between about 6.0 to 7.0) in tuff-air-water systems. Under similar experimental conditions, the addition of glass results in more alkaline solutions (pH values between 7.0 and 9.0). These results are interpreted to indicate that, at high radiation levels (2×10^5 rads per hour), measurable nitrogenous acids are formed.

2.3.3.4 Current Status of Postclosure Rock Characteristics Technical Issues

Based on the summary of EA findings and the review of information obtained since the EA, this section addresses each of the previously identified technical issues to determine if new information supports previous findings and if a higher-level suitability finding can be supported.

<u>Technical Issue 1: Thermomechanical Alteration</u>

A substantial amount of data describing the thermomechanical characteristics of the rock in the potential repository horizon has been collected via laboratory and field investigations, and numerous modeling studies have been performed. Moreover, for tests conducted at G-Tunnel, the thermomechanical response of the rock has been close to that predicted by numerical models. In the laboratory and field tests, no rock deformations or changes in the thermomechanical properties of the rock have been observed that cannot be accommodated using RAT.

Time-dependent thermomechanical behavior has not been extensively investigated. High stress levels and temperatures over time, however, are expected in only the small portion of the rock mass near the free faces of the openings, and these are not expected to pose rock stability problems that cannot be addressed using RAT.

Work completed since the EA continues to support the lower-level finding that the thermomechanical characteristics of the host rock and surrounding units are expected to permit compliance with containment and isolation requirements.

Technical Issue 2: Hydrologic and/or Geochemical Alteration

Hydrologic studies since the EA have focused on episodic fracture flow. Hydrologic alteration of the characteristics of rock in the proposed repository horizon may occur only in fractures and is expected to be minor. The possible alteration includes minor dissolution followed by precipitation of minerals that may produce healing of some fractures and cracks, tending to strengthen the rock while having a small effect on transport properties. These studies have not included fluid-mechanical coupling. Changes in the mechanical characteristics, such as creation of cracks, extension of fractures and/or joints, and motion along joints, may alter the permeability field and consequently influence fluid flow. Conversely, changes in fluid saturation, that may be due to episodic fracture flow into regions of rock that are above the boiling point, will cause increases in pore pressure that may cause motion in the rock mass. Laboratory, field and modeling studies are needed to investigate the potential for these interactions to influence the rock characteristics. Geochemical studies indicate that at elevated temperatures the mineralogy of the rock in the repository will remain generally stable and that the cristobalite-phase transformation will result in only minor changes in a small volume of the total rock mass of the repository.

Information acquired since the EA continues to support the lower-level finding that the hydrologic and geochemical characteristics of the potential host rock and surrounding units at Yucca Mountain are expected to permit compliance with containment and isolation requirements.

Technical Issue 3: Radiation-Induced Alteration

To date, the effect of radiation on the geomechanical properties of rock from the potential repository horizon has not been determined. However, radiation is expected to have a negligible effect on the geomechanical behavior. This conclusion is based on the work of Durham et al. (1986), which showed no statistical effect of radiation on strength or modulus of granitic rocks, and on the self-shielding effect that will limit radiation damage to the first few centimeters of rock surrounding an opening. Additional experiments similar to those conducted by Durham et al. (1986) on samples of rock from the potential host rock would strengthen this conclusion. Experiments to confirm the effect of radiation on tuff-air-water-waste systems may also strengthen this conclusion.

2.3.3.5 Conclusions and Recommendations for Future Postclosure Rock Characteristics Activities

The consensus of the Core Team is that the available evidence continues to support a lower-level (Level 3) finding that the characteristics of the potential host rock at the Yucca Mountain site will accommodate the thermal, chemical, mechanical, and radiation stresses induced by a repository, as well as the interactions expected among the waste, host rock, ground water, and engineered components. Furthermore, it appears an EBS that will meet applicable release limits can be developed using RAT. Given the previously discussed uncertainties, however, a higher-level suitability finding is not supported at this time.

Discussion

There are two areas of additional information that are necessary to support a higher-level suitability finding for this qualifying condition: a more mature EBS design, and the response of thermally-stressed repository-scale underground excavations.

Engineered System Design. Conclusions about the Rock Characteristics Guideline can be strengthened when the design of the waste packages and other components of the engineered system reach a level of maturity that allows an explicit evaluation of the interactions between the configuration, materials of construction, and the host-rock and ground-water characteristics of the site. The flexibility, as presently envisioned, in the selection of the waste stream characteristics, design concepts and engineered-component materials tend to make the determination of qualification with this guideline less constrained by design details.

Repository-Scale Underground Excavations. Current plans include at least one major opening, of a size that is representative of the scale of the repository excavations, in the host rock. This excavation, together with any other construction features that are components of the engineered system should be evaluated under conditions that simulate the maximum stresses that will be imposed by the emplaced waste. This activity will provide information that is expected to confirm that the rock characteristics, as inferred from predictive modeling and laboratory and field tests, are such that a stable underground structure can be achieved with RAT. Moreover, information obtained from evaluation of the response of this excavation should be used as part of the calibration and validation process for predictive models that will be used to evaluate performance that depends on post-emplacement rock characteristics.

The above items indicate that a more advanced design of the engineered system than currently available will be needed to support a higher-level finding for this guideline. Similarly, excavation of the exploratory studies facility and observation of the response of the rock materials and openings to anticipated loads will be needed to confirm the response of the underground facility under representative repository conditions. Note that the NRC's requirement for continued testing and observation during the operational period of a repository, and the maintenance of the option for retrieval, addresses exactly this area of concern.

2.3.4 CLIMATIC CHANGES TECHNICAL GUIDELINE

2.3.4.1 Statement and Discussion of Qualifying Condition

Qualifying Condition [10 CFR 960.4-2-4(a)]: "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."

Discussion. The qualifying condition for this guideline is concerned with the potential effects of future climatic conditions on the waste-isolation capability of the site. The guideline is based on the expectation that flowing water, occurring either as surface water or as ground water, will be the principal mode for radionuclide transport and release to the accessible environment. Consequently, the major effects of climatic change on waste isolation are expected to be mediated by the regional and site hydrologic systems. This interpretation of the qualifying condition is affirmed by the statements of the two favorable and the two potentially adverse conditions associated with this guideline. Table 2-6 lists these conditions and summarizes the findings relative to these conditions presented in the Environmental Assessment (EA) (DOE, 1986). The favorable condition [§960.4-2.4(b)(1)] considers the site to be favorable if the potential effects of climatic change on the surface-water system would not adversely affect waste isolation at the site during the next 100,000 years. The potentially adverse conditions [§960.4-2.4(c)(1) and (2)] consider the potential during the next 10,000 years (1) for a climatic-induced water-table rise sufficient to inundate a repository in the unsaturated zone and (2) for possible climatic-induced effects on the properties, processes, and state of the subsurface geohydrologic system that could lead to radionuclide transport to the accessible environment.

2.3.4.2 Approach for Climatic Changes Evaluation

2.3.4.2.1 Identification and Basis for Climatic Changes Technical Issues

Specific technical issues that need to be addressed to evaluate the Yucca Mountain site with respect to this guideline include site-specific assessments of (1) the rate and magnitude of future climatic changes, (2) the effects of climatic changes on the surface and subsurface geohydrologic systems (including multiphase processes), and (3) the possible consequences of these effects for waste isolation. Defining and quantifying the linkage between climate and the hydrologic systems will be of primary importance for addressing these issues.

Climatic variables, in particular precipitation and ambient air temperature, together with surface characteristics, for example, topography and the hydrologic properties of the surficial materials, are the principal controls that define the surface-water system in the Yucca Mountain region and determine the movement of water into the subsurface geohydrologic system at the Yucca Mountain site. More specifically, this land-surface boundary

Table 2-6. Summary of Environmental Assessment Findings for Climatic Changes (10 CFR Part 960.4-2-4) (DOE, 1986)

Condition	DOE Finding
FAVORABLE CONDITIONS	
1. A surface-water system such that expected climatic cycles over the next 100,000 year would not adversely affect waste isolation.	The evidence indicates that this favorable condition is present at Yucca Mountain: regional and site surface-water systems probably have been the same for several-hundred thousand years; expected climatic changes will not significantly change surface water systems.
2. A geologic setting in which climatic changes have had little effect on the hydrologic system throughout the Quaternary Period.	The evidence indicates that this favorable condition is not present at Yucca Mountain: Quarternary climates were probably not substantially different from modern climates; however, increased flux and higher water tables probably occurred within the geologic setting during the Quaternary Period.
POTENTIALLY ADVERSE CONDITIONS	
1. Evidence that the water table could rise sufficiently over the next 10,000 year to saturate the underground facility in a previously unsaturated host rock.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: there is no evidence that the water table was ever as high as the proposed repository level; climatic changes are not expected to cause sufficient water-table rise to flood the repository.
2. Evidence that climatic changes over the next 10,000 year could cause perturbations in the hydraulic gradient, the hydraulic conductivity, the effective porosity, or the ground-water flux through the host rock and surrounding geohydrologic units, sufficient to significantly increase the transport of radionuclides to the accessible environment.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: increased precipitation could increase unsaturated zone flux, but major changes in hydraulic conditions are not expected over the next 10,000 year. If flux in the host rock was much higher than present, the site would still be expected to meet Environmental Protection Agency (EPA) limits at the accessible environment in 10,000 year.

Table 2-6. Summary of Environmental Assessment Findings for Climatic Changes (10 CFR Part 960.4-2-4) (DOE, 1986) (continued)

Condition	DOE Finding
QUALIFYING CONDITION	
The site shall be located where future climatic conditions will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.	Existing information does not support the finding that the site is not likely to meet the qualifying condition (Level 3): expected climatic changes will not cause significant changes in surface drainage; unsaturated-zone flux may increase, and the water-table altitude may rise, but radionuclide releases are not likely to exceed the release limits.

condition and the configuration of the underlying water table determine the spatial and temporal distribution of moisture within the unsaturated zone at the site. Of principal concern for waste isolation in the unsaturated zone will be the presence of liquid water at the repository horizon that could come in contact with emplaced waste, cause the release of water-soluble or gas-phase radionuclides from the waste, and, subsequently, transport radionuclides in solution to the accessible environment. The evaluation of the effects of future climatic conditions on waste isolation in the unsaturated zone, therefore, will require the development of quantitative models to predict (1) probable (as well as possible extreme) climatic changes that could occur during the next 10,000 years and (2) the response of the unsaturated-zone geohydrologic system to such changes. In addition, a radionuclide source-term model will be needed to predict possible in situ radionuclide releases from emplaced waste to evaluate the likelihood for gas-phase or ground-water transport of radionuclides to the accessible environment. Model predictions of future events and conditions are, however, expected to involve considerable uncertainty; consequently, definitive resolution of the technical issues pertaining to this guideline using strictly deterministic methods may not be appropriate. Instead, reliance on bounding calculations, sensitivity analyses, and probabilistic methods may be necessary in order to estimate maximal and expected consequences of future climatic change. Those possible climatic changes that could lead to increased vertically downward ground-water flux through the repository horizon or to significant local water-table rise are of primary concern with respect to possible climatic effects on waste isolation in the unsaturated zone.

In formulating the guideline, the U.S. Department of Energy (DOE) recognized the difficulty of accurately predicting future climatic conditions and their potential effects on waste isolation. Consequently, the second favorable condition associated with this guideline (Table 2-6) directs the DOE to consider the local, regional, and global climatic patterns that occurred during the Quaternary Period as indicators of the possible magnitude and direction of future climatic changes at the site. Resolution of the guideline, therefore, will be based, in part, on analyzing and seeking evidence for both past climatic changes and the effects of these changes on the site and regional geohydrologic systems. Presumably, if empirical data can demonstrate that the effects of past and present climatic conditions have not produced environments at the site that would fail to satisfy the qualifying condition, then it may be considered unlikely that future climatic conditions will do so.

The guideline does not provide specific criteria by which to assess possible effects on waste isolation arising from climatic-induced changes in the surface-water regime (e.g., increased streamflow and the creation or enlargement of lakes). As will be discussed later in this guideline evaluation, however, the effects of the surface-water system on waste isolation in the unsaturated zone at the Yucca Mountain site are effectively subsumed under the Erosion Guideline (§960.4-2-5) and the potentially adverse condition [§960.4-2-4(c)(2)], which is concerned with the effects of climatic change on the subsurface geohydrologic system.

2.3.4.2.2 Information or Actions to Resolve Climatic Changes Issues

The following information or actions are needed to resolve the issues associated with this guideline:

1. Characterization of the present state of the site and regional hydrologic systems, including the spatial distribution of net infiltration at the site

2. Reconstruction of past (Quaternary) climatic conditions and changes based on the analysis and interpretation of paleoenvironmental data and the results from climate models

3. Evaluation of the effects of past climatic changes on the site and regional hydrologic systems

4. Predictive (probabilistic) modeling of possible future climatic change at the site

5. Predictive hydrologic modeling to assess probable effects of future climatic change on the site and regional geohydrologic systems, including both liquid and gas phases in the site unsaturated-zone system

6. Predictive multiphase flow and transport modeling to assess possible impacts of future climatic change on waste containment and isolation at the site.

Action (1) establishes the set of initial conditions needed to predict future hydrologic system change and evolution. The initial conditions are a condensed history of previous system evolution as elucidated by actions (2) and (3). Actions (4) and (5), which will be based on the initial conditions and model calibrations derived from the evidence for and the effects induced by past climatic change, will provide quantitative predictions of future climatic regimes and geohydrologic-system evolution. Action (6) considers the effect on waste isolation as part of an evaluation of expected overall repository-system performance. Although past climatic conditions may provide bounds on likely future climate change, there is no assurance that climatic change need be cyclic and, therefore, that past climatic regimes necessarily will repeat in the future. For example, the effects of human activity on climate (e.g., hypothesized global "greenhouse" warming), which may disrupt otherwise naturally occurring climatic evolution, will need to be taken into account.

2.3.4.3 Status of Current Climatic Changes Information

2.3.4.3.1 Summary of Environmental Assessment Findings for Climatic Changes

The body of evidence that was available at the time of the EA was considered insufficient to support higher-level findings for this guideline. Nevertheless, the EA concluded that the Yucca Mountain site is unlikely not to comply with the Environmental Protection Agency (EPA) release limits for liquid-phase radionuclide transport to the accessible environment under those climatic conditions that can be expected to occur during the next 10,000 years. This lower-level suitability finding was based primarily on the present-day aridity of the site and region, evidence indicating that climatic conditions did not depart appreciably from modern during the Quaternary, and the expectation that significant climatic change is unlikely to occur during the next 10,000 years. The results of the paleoclimate and paleohydrology studies cited in the EA indicate that there has been a general trend toward warmer and drier conditions within the Yucca Mountain region since the last Wisconsin glacial maximum, which occurred about 18,000 years ago. This overall trend, however, has been interrupted by apparent "micropluvial" episodes consisting of relatively short-duration intervals of cooler and wetter conditions. For example, as cited in the EA, plant-community distributions, as inferred from pack-rat middens, indicate the occurrence of at least one such episode in early Holocene time, during which average annual temperature in the Yucca Mountain region may have been about 2°C lower and average annual precipitation 100 percent greater relative to present-day conditions.

The EA reports that the major effects on geohydrology in the Yucca Mountain region that could be produced by climatic change include (1) alteration and possible reconfiguration of the surface-water drainage systems, (2) changes in the quantity and spatial distribution of recharge to the regional ground-water flow system, (3) spatial relocation of the sites of ground-water discharge, (4) changes in potentiometric-surface altitude and gradients, and (5) redistribution of moisture content and flux within the thick unsaturated-zone environments within the region. The potential effects that would be induced by the occurrence of pluvial conditions are of primary concern because increased precipitation could lead to increased recharge, higher water-table altitudes, and increased moisture content in the unsaturated zone at the Yucca Mountain site. The principal consequences for waste isolation in the unsaturated zone could include greater ground-water fluxes through the repository horizon and shorter ground-water travel times from the repository to the accessible environment. The timing and ultimate consequences for waste isolation of any sequence of events induced by climatic change will depend on the magnitude and duration of the change and the time required for the surface-water and ground-water hydrologic systems to respond to such change. The uncertainties associated with predicting future climatic changes and hydrologic-system response to these changes constitute major issues that must be addressed to complete the evaluation for this guideline.

2.3.4.3.2 Review of Climatic Changes Information Obtained Since the Environmental Assessment

Most of the studies pertinent to this guideline that have been conducted since the EA have been concerned with identifying the major features and aspects of climatic and hydrologic conditions that prevailed in the southern Great Basin since the mid-to-late Quaternary Period. These studies, which are summarized below, consider a broad range of evidence and involve a variety of approaches and analytic techniques. Although these studies generally substantiate the results presented in the EA, the more recent data and analysis differ in detail from the EA regarding the magnitude and timing of past climatic change and the possible hydrologic effects of these changes. Most of the evidence pertains to events and conditions that have occurred since the late Pleistocene Wisconsin glaciation reached its maximum about 20 to 18 ka (thousand years before present) in the western United States (Dorn et al., 1990). These studies indicate a general hydroclimatic trend toward warmer and drier conditions throughout the southern Great Basin since late Wisconsin time punctuated, however, by cooler and wetter "micropluvial" episodes that lasted for a few hundred to, perhaps, as much as 1,000 years. Because the longer-term record is not well preserved, there remains little information on pre-Wisconsin Quaternary hydroclimatic conditions and events within the Great Basin and the Yucca Mountain region. Some aspects of this longer-term hydroclimatic record, however, appear to be reflected in the surface and subsurface hydrologic record (Huber, 1988; Winograd and Szabo, 1988), and isotope data from secondary calcite in borehole core samples at Yucca Mountain may constitute evidence for water-table fluctuations, possibly induced by climatic variability, that may have occurred during the interval from about 26 to 400 ka (Whelan and Stuckless, 1991). Although little work has been done since the EA to evaluate possible future climatic conditions and consequent hydrologic effects in the Yucca Mountain region, the development of increasingly detailed reconstructions of hydroclimatic conditions that prevailed during the late Quaternary in the western United States provide a basis for testing and calibrating climate models to predict future conditions and events.

2.3.4.3.2.1 Paleoclimate

Past regional and global climatic conditions and variability are inferred primarily from the analysis and interpretation of paleoenvironmental data. Sources of paleoenvironmental data in the western United States include lake-level records from present and former lakes, lake-bottom sediment cores, macrofossil assemblages from packrat middens, and stratigraphic pollen sequences. Data and analyses that have become available since the EA indicate that a complex regional pattern of climatic conditions and change developed over the western United States following the last Wisconsin glacial maximum 18 to 20 ka. The results of global-scale climate modeling (COHMAP, 1988) support the hypothesis that these climatic conditions and changes occurred in response to the combined effects of increasing summer insolation in the Northern Hemisphere and the initial presence and subsequent retreat of the continental ice sheets in North America. A general trend toward warmer and drier conditions in the Yucca Mountain region during the late Quaternary continues to be supported. Presently available data, however, are not sufficiently well distributed spatially to permit detailed inferences regarding past climatic conditions at the Yucca Mountain site; the discussion that follows, however, assumes that past climatic conditions at Yucca Mountain were similar to those that prevailed elsewhere in the Great Basin.

Lake-level chronologies for closed-basin late-Pleistocene lakes in the Great Basin have been developed by Benson and Thompson (1987), Benson et al. (1990), Dorn et al. (1990), and Stine (1990). These studies indicate that the period from about 30 to 18 ka prior to and during the last Wisconsin glacial maximum was a time of persistent moderate-to-low lake levels suggesting cool, dry climatic conditions then prevailed in the Great Basin. Lake-level highstands were attained between about 16 and 12 ka, which Dorn et al. (1990) attribute to the occurrence of warmer and wetter conditions that developed at the time of and continued following alpine glacial retreat in the region. Evidence indicates that several lakes underwent lake-level oscillations between about 15 and 14 ka, which may have been responses to localized climatic variability during this time. Most of the lakes experienced nearly synchronous recession between about 14 and 13.5 ka, apparently in response to the widespread occurrence of effectively drier conditions. This was followed by a period of lake-level stability until about 11.5 to 10 ka when minor enlargement occurred, apparently in association with a terminal Pleistocene glacial advance in the Great Basin (Dorn et al., 1990). Except for minor oscillations, the lakes have remained at low levels throughout the Holocene. Based on a study of Mono Lake, California, Stine (1990) suggests that the Holocene lake-level oscillations probably occurred in response to hydroclimatic-induced differences in lake inflow and evaporation.

On the basis of analyses of sedimentation rates, organic-carbon contents, and faunal assemblages in cores of lake-bottom sediments in Walker Lake, Nevada, Yang (1989) and Bradbury et al. (1989) have inferred a hydroclimatic chronology for the Walker Lake basin extending from the present to about 30 ka. Walker Lake is in west central Nevada about 300 km northwest of the Yucca Mountain site and is a closed-basin remnant of former Pleistocene Lake Lahontan. Because Walker Lake is situated in a closed basin, the rate of lake-bottom sedimentation is assumed to be related directly to precipitation and runoff within the drainage basin, and the production of organic carbon and the occurrence of fauna are assumed to be related to lake-water temperature and salinity. Corrected radiocarbon dates were obtained from selected horizons on cores penetrating as much as 50 m of lake-bottom sediments and extending in time from modern to about 40 ka or older. Microfossil assemblages present in the cores included diatoms, ostracodes, and pollen. The core data indicate that low rates of sedimentation and organic-carbon production occurred during the period between 21 and 30 ka, which Yang (1989) interpreted to imply cool, dry climatic conditions within the drainage basin. The microfossil data (Bradbury et al., 1989) further indicate the presence of shallow saline conditions during this time. Increased rates of sedimentation commencing about 20 ka apparently indicate the post-glacial filling of Lake Lahontan, which attained its highstand about 13 ka (Benson et al., 1990; Dorn et al., 1990). Microfossils are virtually absent from the cored interval between 26 and 16 m, which is estimated to span the time period from about 16 to 5 ka, and this, combined with sediment properties, suggests the occurrence of a playa environment during this time. Rapid filling of Walker Lake occurred between about 5.5 and 4.5 ka and may have been the result of a rediversion of the Walker River into Walker Lake. The record also indicates a period of low lake levels between about 3 and 2 ka followed by a period of slow filling that may be attributed to climatic change. The faunal data suggest that salinity and, possibly, lake levels fluctuated throughout the Holocene and may reflect climatic variability within the region.

On the basis of available pollen data from sites in the southwestern United States, including two in southern Nevada, Hall (1985) has constructed a preliminary vegetational history spanning the past 40,000 years. The data indicate that vegetation zones were 900 to 1,400 m lower during the Wisconsin glacial period relative to present altitudes. The transition from glacial to post-glacial vegetation occurred between about 14 and 12 ka. The vegetation data also indicate that middle Holocene time between about 7 and 5 ka was characterized by a period of considerably drier and warmer climatic conditions relative to both modern and average Holocene conditions. This conclusion is supported by middle Holocene macrofossil records from pack rat middens in the southern Mojave Desert that indicate the occurrence of increased aridity relative to present-day conditions during the period between 6.8 and 5.06 ka (Spaulding, 1991).

Using effective moisture (precipitation minus evaporation) and temperature as climatic indicators, Thompson et al. (1992) have developed a chronology for the qualitative nature, direction, and regional distribution of climatic change in the western United States based on 3,000-year intervals centered on 18, 12, 9, and 6 ka. These times are coincident with the approximate timing of major paleoenvironmental and paleoclimatic change and were selected in order to facilitate comparisons with the results obtained from numerical climate modeling. The paleoenvironmental data and the climate-model results indicate that the full-glacial climate at 18 ka in the northern Great Basin was characterized by colder temperatures and greater effective moisture relative to present-day conditions. However, temperatures in the Yucca Mountain region, which is located in the southern Great Basin, may have remained mild with enhanced effective moisture as a result of increased precipitation in the region relative to present conditions. The Cordilleran Ice Sheet and associated alpine glaciers had retreated by 12 ka, and the late-Pleistocene lakes had advanced to and receded from their respective highstand levels. The data suggest that conditions of somewhat greater effective moisture and cooler temperatures relative to present-day conditions may have prevailed in the Yucca Mountain region at this time. At about 9 ka, summer insolation in the northern hemisphere achieved its maximum and indications are that a period of increasing temperature and aridity commenced in the Yucca Mountain region at about this time. Middle-Holocene time at about 6 ka apparently was a time of maximum temperature and aridity relative to present-day conditions in the Yucca Mountain region and was followed by a general late-Holocene trend toward present-day conditions. The overall conclusion suggested by both the paleoenvironmental data and the climate-modeling results as synthesized by Thompson et al. (1992) continues to be that the Yucca Mountain region probably has not experienced appreciably different climatic conditions during the past 20 thousand years from those that prevail in the region today.

The extent to which climatic change during the Quaternary may serve as a guide for predicting future climatic change in the Yucca Mountain region depends partly on the expectation that climatic change is cyclic and, therefore, that past climatic conditions will recur within the Yucca Mountain region. Winograd et al. (1988) obtained a chronologic record of relative ^{18}O abundances for the period 50 to 310 ka based on analysis and uranium-series dating of vein calcite from Devils Hole, southern Amargosa Desert, Nevada, about 50 km south of the Yucca Mountain site. The major features of the ^{18}O time-series record from Devils Hole correlate well with the ^{18}O record obtained from marine sediments and Antarctic ice cores. In particular, the Devils Hole data appear to record the major abrupt global warming episodes that occurred at about 130, 225, and 240 ka as inferred from the marine data. The vein-deposit material that was analyzed, however, was not sufficiently young to register the onset of the last interglacial, which the marine ^{18}O data indicate to have occurred at about 16 ka. Spectral analysis of the Devils Hole ^{18}O data indicate the occurrence of cyclic features within the climate record for the southern Great Basin with periodicities ranging from about 126 to 23 thousand years, as predicted by the astronomically based Milankovitch theory of climate cycles. The Devils Hole data do not, however, support the Milankovitch theory with regard to the timing of past major climatic events. Consequently, although the Devils Hole data clearly indicate that cyclical climate variation probably has occurred and is likely to continue to occur in the Yucca Mountain region, these data do not establish a firm basis for predicting the absolute duration and timing of likely future climatic change within the region, that is, during the next 10,000 to 100,000 years.

2.3.4.3.2.2 Paleohydrology

A study of the late Cenozoic evolution of the upper Amargosa River drainage system by Huber (1988) indicates that the major features of the surface-water drainage system in the Yucca Mountain region developed during mid-to-late Miocene time and have undergone little modification since that time. The major stream channels within the system drain volcanic highlands that are located north of Yucca Mountain. These highlands are the remnants of a caldera complex that was active during middle Miocene time and was the source of the tuffs underlying Yucca Mountain. On the basis of geologic and geomorphic information, Huber (1988) concluded that the Upper Amargosa drainage system was established in its present configuration soon after the terminal phase of caldera collapse and resurgent-dome formation ended about 11 mya. No significant change has occurred within the system since that time, although a transition from alluvial-fan construction to fan-head incision has apparently occurred at a number of sites within the system. Preliminary uranium-series age dating indicates that the onset of alluvial-fan incision occurred within the past 500,000 years. Because this transition from fan aggradation to fan incision appears to have occurred pervasively and simultaneously throughout the drainage system, Huber (1988) suggests that climatic change, specifically a change toward increasingly arid conditions within the drainage system, probably is the most plausible cause for this change in regimen. This interpretation is consistent with the work of Winograd and Szabo (1988), who suggest that the southern Great Basin has become progressively more arid since mid-Quaternary time, possibly as a result of a "rain-shadow" effect produced by the uplift of the Sierra Nevada and the Transverse ranges in California. With respect to the effects of past climatic change on the geohydrology of the Yucca Mountain site, the most important inference to be drawn from Huber (1988) is that the surface-water system, and, by implication, the ground-water system, apparently have been essentially stable for the past 11 million years. Although available evidence indicates the occurrence of fluctuations in the regional climate during the Quaternary, there is no evidence that these fluctuations translated into major effects on the surface or subsurface hydrologic systems at or near Yucca Mountain. On the other hand, present evidence suggests a general trend towards increasingly arid conditions within the southern Great Basin that could be contributing to both apparent regional water-table declines and changes in the surface-water erosional regime.

Springs at Ash Meadow, in the Amargosa Desert, Nevada, and at Furnace Creek Wash, in east-central Death Valley, are considered to be sites of ground-water discharge from the regional deep carbonate-rock aquifer that underlies south-central Nevada (Winograd and Thordarson, 1975). Based on examination and analyses of vein calcite, tufa, and other remnant spring-discharge features, Winograd and Szabo (1988) concluded that the water-table altitude in the carbonate-rock aquifer at these discharge sites (and, by extension, the altitude of the up-gradient potentiometric surface) has declined progressively throughout middle and late Pleistocene time. Uranium-series dating of vein calcite indicate apparent rates of water-table decline ranging from 0.02 to 0.08 m per thousand years at Ash Meadows and from 0.2 to 0.6 m/ka at Furnace Creek Wash. Winograd and Szabo (1988) suggested that a combination of climatic change and tectonic processes may be responsible for producing these apparent water-table declines. As mentioned previously, evidence and interpretations cited by Winograd and Szabo (1988) and in the EA indicate a trend towards increasingly arid conditions within the southern Great Basin throughout the Quaternary.

A trend toward increasing aridity in the region also is supported by evidence cited by Quade (1986) and Quade and Pratt (1989) who interpret the presence of widespread fine-grained deposits in the upper Las Vegas Valley, southern Nevada, to be the sites of former spring-supported marsh environments. Radiocarbon dating of organic material within these deposits indicate that the springs were active as early as 30 ka and had undergone progressive down-valley desiccation and abandonment by about 9 ka. Packrat midden data analyzed by Spaulding (1991) indicate that maximal aridity relative to present-day conditions in the northern Mojave Desert and, by implication, in the Yucca Mountain region, occurred during middle Holocene time, 7.8 to 4 ka. Increasing aridity would be expected to reduce recharge to the carbonate-rock aquifer and, consequently, to lead to region-wide decline of the potentiometric surface, reduced ground-water discharge from the aquifer, and water-table declines at the discharge sites. The water-table declines considered by Winograd and Szabo (1988) refer specifically only to the "Lower carbonate aquifer" of Winograd and Thordarson (1975, Table 1). Because this regional aquifer is thought to exert major control on the altitude of the water table in the overlying Cenozoic welded-tuff and valley-fill aquifers (Winograd and Thordarson, 1975, pp. C53-C63 and Pl. I), regional decline of the potentiometric surface in the deep carbonate-rock aquifer will be accompanied, over time, by corresponding water-table declines in the overlying shallow aquifers. In addition to secular decline, fluctuations in water-table altitudes are expected to occur in response, for example, to micropluvial episodes superimposed on the long-term climatic trends. Considering that progressive water-table decline due to regional base-level lowering is likely to continue into the geologic future (100,000 to 1,000,000 years) and allowing for episodic water-table fluctuations, Winograd and Szabo (1988) concluded that future climatic-induced water-table rises would be unlikely to inundate a nuclear-waste repository located a few tens to a hundred or more meters above the present water table in the Yucca Mountain region.

Although the data and interpretations presented by Winograd and Szabo (1988) indicate progressive decline of water-table and potentiometric-surface altitudes in the deep carbonate-rock aquifer in the Yucca Mountain region since mid-Pleistocene time, these results cannot be used directly to estimate former water-table altitudes in the overlying shallow Tertiary volcanic-rock aquifer at the Yucca Mountain site. Levy (1991), however, has used mineralogic, textural, geochronologic, and structural data to develop a preliminary conceptual history of water-level change within the sequence of tuffs underlying Yucca Mountain. On the basis of the hypothesis that extensive zeolitization of the nonwelded tuffs at Yucca Mountain occurred diagenetically during prolonged periods of submersion below the water table and on the present-day faulted configuration of the transition zone between vitric and zeolitic nonwelded tuffs, Levy (1991) concluded that the maximum water-table altitude relative to the present stratigraphic section at Yucca Mountain was attained during the interval between 11.6 and 12.8 ma (million years before present). Levy (1991) also concluded that subsequent to that time the water table beneath central Yucca Mountain probably has not been sustained for prolonged periods at altitudes greater than 60 m above its present configuration.

2.3.4.3.2.3 Effects of Future Climatic Changes

Regarding net infiltration from precipitation to represent the cumulative effects of climatic change on the subsurface geohydrologic system, Long (1990) constructed a simplified model for net infiltration into the unsaturated zone at Yucca Mountain based on the assumption of a constant mean annual rate of storm occurrence and exponentially distributed storm duration and precipitation rate. The model was developed as part of an effort to demonstrate the feasibility of applying risk-based methods to evaluate the expected performance of geologic repository systems, and the simplifications on which the net-infiltration model was based were consistent with the limited scope and objectives of the larger effort. In developing the model, Long (1990) assumed that climatic change is cyclic and that pluvial conditions, therefore, are likely to occur in the Yucca Mountain region during the next 10,000 years with resultant increased storm intensities and durations. Net infiltration was assumed to be proportional to storm intensity for those storms whose duration exceeded a specified threshold value. The rate of net infiltration was considered to be spatially uniform and constant over time, and it was further assumed that net infiltration would be translated instantaneously into net sustained percolation flux over the full vertical extent of the unsaturated zone. Probability distributions for present and future net infiltration were constructed by Monte Carlo simulations based on 1,000 storm events with allowance for differences between summer and winter events and between pluvial and post-pluvial climatic regimes. These distributions yielded mean net infiltration rates of 1.04 mm/year under simulated present conditions and 1.5 mm/year for simulated conditions occurring during the next 10,000 years. Although the quantitative results of this highly simplified model may not provide a completely realistic physical representation of future conditions and processes at Yucca Mountain, this approach demonstrates the application of probabilistic-based methods for evaluating expected effects of climatic change on the unsaturated-zone geohydrologic system at the Yucca Mountain site.

2.3.4.4 Current Status of Climatic Changes Technical Issues

Data collected and analyzed since the EA was issued generally support the evaluations and conclusions presented in the EA with respect to the potential effects of climatic change on the geohydrology of the Yucca Mountain region. In addition to the information presented in the EA, evidence for climatic variability during the past 30,000 years, including at least one micropluvial episode that may have occurred between 4,500 and 5,500 years ago, is implied by the Walker Lake core data as interpreted by Yang (1989). However, although the evidence suggests the occurrence of past climatic variability, the effects of this variability on the surface and subsurface hydrologic systems at Yucca Mountain have not been quantitatively assessed. The analysis of late Cenozoic evolution of the upper Amargosa River drainage system performed by Huber (1988) indicates that the major features of the surface-water system at and near Yucca Mountain have remained largely unchanged over the past 11 million years except for an apparent transition from alluvial-fan deposition to alluvial-fan incision throughout the region, which Huber (1988) suggests may be attributed to increasing aridity during late Pleistocene time. The paleospring data analyzed by Winograd and Szabo (1988) imply progressive lowering of regional water-table altitudes since mid-Pleistocene time, which they also attributed, in part, to increasing aridity within the southern Great Basin. On the basis of inferences from geochemical and geologic data, Levy (1991) concluded that the water table beneath central Yucca Mountain attained its maximum altitude relative to the present stratigraphic section and commenced to decline shortly after deposition of the 12.8 million year-old Topopah Spring Member of the Paintbrush Tuff and, since that time, has not stood higher than 60 m above its present altitude for sustained periods. The work of Huber (1988), Winograd and Szabo (1988), and Levy (1991) considers long-term paleohydrologic trends and does not consider the possible short-term effects (lasting a few thousand years or less) on Yucca Mountain geohydrology that could be induced, for example, by micropluvial episodes, such as may have occurred 4,500 to 5,500 years ago as implied by the data and interpretations of Yang (1989).

The results obtained by the studies reviewed in this guideline evaluation do not alter the findings presented in the EA with respect to the possible consequences of future climatic change on waste isolation at the Yucca Mountain site. On the basis of the results of the studies by Winograd and Szabo (1988) and Levy (1991), the consensus of the Core Team is that the lower-level finding presented in the EA has been strengthened. It is likely that the water table at the Yucca Mountain site remained below the potential repository horizon throughout the Quaternary, and it is very unlikely to rise sufficiently during the next 10,000 years because of climatic change to inundate a facility constructed at the potential repository horizon.

2.3.4.5 Conclusions and Recommendations for Future Climatic Change Activities

The consensus of the Core Team is that available evidence and analyses do not presently support a higher-level finding with respect to this guideline. Although considerable information is becoming available regarding past climatic conditions in the Yucca Mountain region, virtually no detailed analyses of the possible effects of future climatic changes have been performed to date. The development of quantitative methods and models to predict the occurrence, magnitude, and direction (e.g., wetter or drier and warmer or colder) of probable climatic change in the Yucca Mountain region during the next 10,000 year needs to be completed, and the effects that predicted climatic change are likely to produce on the hydrologic systems and waste isolation at the Yucca Mountain site need to be quantitatively assessed.

The following sections describe three areas of study that will provide important information for evaluating this guideline.

2.3.4.5.1 Future Climatic Change

Models that solve the equations describing large-scale atmospheric dynamics are needed to predict future climatic change. These models will need sufficient spatial resolution to permit prediction of local or regional climatic conditions in response to global forcing and boundary conditions. The prediction of future climates also must account for the effects on long-term climate that may be induced by human activity, e.g., the introduction of greenhouse and other climate-affecting gases into the atmosphere. Consequently, a number of possible, but realistic, climatic scenarios, and their estimated probabilities of occurrence will need to be identified and considered as part of the evaluation for this guideline. One such approach directed specifically at developing scenarios and examining the consequences for possible global climatic change in response to present and future greenhouse-gas emmissions is that being taken by the Intergovernmental Panel on Climate Change (IPCC, 1990).

Wendland (1991) points out that the spatial resolution of currently available general circulation models (GCMs) is not sufficient to provide accurate predictions of climatic conditions at scales appropriate to the Yucca Mountain region. However, Dickinson et al. (1989) have developed and applied, with specific reference to the Yucca Mountain site, an approach that may alleviate many of the shortcomings of the GCMs. By embedding a high-resolution regional climate model within a low-resolution GCM, which is implemented to provide the lateral boundary conditions for the embedded model, they were able to reproduce the major seasonal and orographic features of present regional climatic patterns within the western United States. This approach permitted individual hypothetical storm events to be tracked and modeled. In addition, the regional model incorporated techniques for calculating soil-energy and soil-moisture balances that could be interpolated within the regional model domain to yield estimates of net infiltration at the Yucca Mountain site. This approach demonstrates the feasibility of predicting climatic variability within the Yucca Mountain region in response to simulated future global climatic events and trends. Plans for the development and application of climate-modeling techniques with specific application for characterization of the Yucca Mountain site are described by Thompson et al. (1991).

2.3.4.5.2 Effects of Climatic Change on Site Geohydrology

Because hydrologic systems generally respond nonlinearly to changing external or internal conditions, predicting the hydrologic consequences of climatic change generally will not be straightforward. Precipitation is the primary input variable to a hydrologic system, and future changes of precipitation patterns and amounts are the most likely manifestations of climatic change that will affect the hydrology of the Yucca Mountain region. The usual approach is to incorporate precipitation, directly or indirectly, into the boundary conditions or source term as part of a predictive numerical model of the system. Examples include rainfall-runoff models for surface-water systems and ground-water flow models for subsurface unsaturated-zone and saturated-zone systems in which net infiltration and recharge, respectively, are specified as part of the model boundary-condition data. A number of numerical modeling methods have been developed for simulating hydrologic-system response, and these methods probably are adequate to estimate the effects of precipitation change on the hydrologic systems provided that sufficient site data for surface characteristics and hydrologic properties are available. In addition to the boundary-condition data, knowledge of present-day surface and subsurface hydrologic conditions at the site also is needed to provide a sufficient set of initial conditions on which to base the predictive models. The predictive models generally are deterministic in the sense that they yield unique solutions for each specified set of initial and boundary conditions. The preliminary work of Long (1990) demonstrates how probabilistic methods can be coupled with deterministic models to incorporate model and data uncertainty in evaluating the potential effects of climatic change on ground-water flow systems.

2.3.4.5.3 Effects of Climatic Change on Waste Containment and Isolation

By controlling the amounts and rates of water available to enter these systems, climatic change is expected to affect both the surface-water and the ground-water hydrologic systems in the Yucca Mountain region. Of these systems, only the ground-water system is of principal concern at the Yucca Mountain site. Because of present-day aridity in the southern Great Basin, there are no permanent occurrences of surface water at or near Yucca

Mountain, and because radioactive waste at the Yucca Mountain site would be emplaced in the unsaturated zone at depths exceeding 200 m below the land surface, it is unlikely that any permanent or ephemeral surface-water occurrences would directly impact waste isolation at the site. An exception would be the very unlikely occurrence of pluvial conditions that could cause sufficient erosional downcutting by surface water at the site to directly exhume and expose emplaced waste. This possibility, however, is virtually precluded because it would require appreciably higher rates of erosion than are considered to be occurring or could conceivably occur at the Yucca Mountain site, as discussed in Section 2.3.5 of this site suitability report. Indirect effects that could be produced by surface-water occurrences include increased infiltration into the unsaturated zone and increased recharge to the saturated zone. These effects are implicitly subsumed by potentially adverse condition 960.4-2-4 (c)(2) that considers future climatic-induced effects on the overall subsurface geohydrologic system. Furthermore, the geomorphic evidence cited by Huber (1988) indicates that the surface-water system in the Yucca Mountain region has not undergone significant change since its configuration was established during mid-Miocene time. Consequently, the favorable condition 960.4-2-4(b)(1) that is concerned with the long-term stability of the surface-water system with respect to climatic change probably is present at the Yucca Mountain site.

The effects of climatic changes on the subsurface geohydrologic systems, however, may lead directly to consequences that could adversely affect waste containment and isolation in the unsaturated zone at the Yucca Mountain site. Climatic change that would lead to increased effective moisture (precipitation minus evaporation) in the Yucca Mountain region probably would cause increased net infiltration to the site unsaturated-zone geohydrologic system as well as increased recharge to the regional saturated-zone ground-water system. Increased ground-water flux in the unsaturated zone implies that more water could become available to contact emplaced waste and to transport dissolved radionuclides downward from the repository to the underlying saturated zone and subsequently to the accessible environment. Increased ground-water recharge could lead to water-table rise, as well as to higher ground-water velocities, and, thus, shorter ground-water travel times in the saturated zone at the site. Definitive evaluation of these possible effects and consequences at the Yucca Mountain site (or at any geologic-repository site, for that matter) is virtually precluded because of the large uncertainties associated with the data and models needed to deterministically predict future climatic changes and their consequent effects on flow and transport in the unsaturated-zone and saturated-zone geohydrologic systems. Stochastic and probabilistic methods, such as Monte Carlo simulation, may be a viable approach for incorporating and propagating data and model uncertainty quantitatively. An alternative approach, based on inverse methods and sensitivity analyses, however, may be appropriate to establish upper bounds on expected geohydrologic-system response and consequences for waste isolation due to climatic change. For example, tolerable maximal values of ground-water flux through the geohydrologic systems with respect to effects of flux on waste containment and isolation and ground-water travel time could be estimated through ground-water flow and transport modeling. Climate models could then be invoked to evaluate that degree of climatic forcing necessary to produce climatic change from present day conditions sufficient to create these fluxes, and a judgment could then be made whether such climatic change would be plausibly realizable during the 10,000- to 100,000-year repository lifetime. Ultimate resolution of the issues associated with this guideline probably will require a combination of deterministic, stochastic, and inverse methods to adequately bound the problem and to provide a defensible basis for supporting higher-level findings.

2.3.5 EROSION TECHNICAL GUIDELINE

2.3.5.1 Statement and Discussion of Qualifying and Disqualifying Conditions

Qualifying Condition [10 CFR 960.4-2-6(a)]: "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."

Disqualifying Condition [10 CFR 960.4-2-6(d)]: "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."

Discussion. The objective of the Erosion Guideline is to ensure that erosional processes will not degrade the waste-isolation capabilities of the repository site. The site should allow the underground facility to be placed deep enough to ensure that the proposed repository will not be uncovered by erosion or otherwise adversely affected by surface-degradation processes. Estimates of erosion rates will be calculated based on measurements of incision of dated geologic units.

2.3.5.2 Approach for Erosion Evaluation

2.3.5.2.1 Identification of Erosion Technical Issues

The technical issues pertaining to this guideline are derived directly from the qualifying and disqualifying conditions.

- Technical Issue 1

  Based on the Quaternary record, are the nature, rates, and depths of erosion such that, when extrapolated for 10,000 years into the future, they will cause releases of radionuclides to the accessible environment that exceed those allowable under 10 CFR 960.4-1?

- Technical Issue 2

  Is the potential host rock suitable for the construction of a repository at a minimum depth of 200 m below the directly overlying ground surface?

The most important consideration in the first technical issue is whether rates of erosional incision, under the likely range of climatic conditions during the 10,000-year waste-isolation period, are sufficiently high to result in a credible probability that the repository could be exhumed. The geologic units exposed at the surface of Yucca Mountain are of various ages, as old as 14 mya, thereby providing adequate opportunity to reconstruct past rates of erosion by measuring the incision of dated units. Various dating techniques are available, although compatibility of results from complementary methods should be emphasized to gain sufficient confidence in those that are experimental.

Also embedded in the first issue is the consideration as to whether erosion may have other adverse effects on repository performance. Another conceivable way for erosion to adversely affect repository performance would be if a significant change in the positions of channels were to occur so that infiltration might be concentrated to cause a locally high flux of water through the repository. Therefore, channel stability needs consideration by interpretation of both the regional and the site geomorphic history.

The second technical issue can be resolved by evaluating drilling data relevant to the spatial distribution of the potential host rock. Additional considerations are the surface topography, which is available, and the repository design, which is evolving with cognizance of the Erosion Guideline.

2.3.5.3 Status of Current Erosion Information

2.3.5.3.1 Summary of Environmental Assessment Findings for Erosion

The findings reached by the DOE in the Yucca Mountain Environmental Assessment (EA) (DOE 1986) on the qualifying, disqualifying, favorable, and potentially adverse conditions spécified in 10 CFR 960 are given in Table 2-7.

The EA determined that the erosional rates and processes that have operated at Yucca Mountain during the Quaternary Period are very likely to continue for tens of thousands to millions of years into the future and will not adversely affect the waste isolation capabilities of the site (DOE, 1986). Therefore, the DOE made the finding that existing information does not support that the site is not likely to meet the qualifying condition (Level 3).

The DOE also determined that the densely welded Topopah Spring Member of the Paintbrush Tuff is sufficiently thick and deep to allow all portions of the proposed repository to be located in a zone of low lithophysal content, at least 200 m below the surface of the directly overlying ground surface. The EA (DOE, 1986) made the finding that the evidence does not support a finding that the site is disqualified (Level 1).

In the EA, the DOE (1986) also determined that two of the three favorable conditions are present at the site and that the two potentially adverse conditions are not present (Table 2-7). The favorable condition that is not present is that the waste could be emplaced at least 300 m beneath the surface. Although the great depth to the water table at Yucca Mountain would allow the placement of a repository at a minimum depth of 300 m, the nonwelded tuffs available at that depth are believed to be less suitable. Relative to the potential host rock, they have lower thermal conductivity, higher porosity and water content, and are not as freely draining. Additionally, the present design allows for a vertical separation of more than

Table 2-7. Summary of Environmental Assessment Findings for Erosion (DOE, 1986)

Condition	DOE Finding
QUALIFYING CONDITION	
The site shall allow the underground facility to be placed at a depth such that erosional processes acting upon the surface will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.	Existing information does not support the finding that the site is not likely to meet the qualifying condition (Level 3): erosional rates and processes at Yucca Mountain during the Quaternary Period are expected to continue; about 2 million years is the minimum credible time to exhume the repository.
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 m below the directly overlying ground surface.	The evidence indicates that the site is not disqualified: the shallowest parts of the underground facility are more than 200 m below the directly overlying ground surface
FAVORABLE CONDITIONS	
1. Site conditions that permit the emplacement of waste at a depth of at least 300 m below the directly overlying ground surface.	The evidence indicates that this favorable condition is not present at Yucca Mountain: the preferred repository horizon cannot accommodate all waste at depths greater than 300 m within the primary repository area.
2. A geologic setting where the nature and rates of the erosional processes that have been operating during the Quaternary Period are predicted to have less than one chance in 10,000 over the next 10,000 years of leading to releases of radionuclides to the accessible environment.	The evidence indicates that this favorable condition is present at Yucca Mountain: minimum depth to the repository is about 230 m; there is only one chance in 10,000 of removing 5.5 m (18 ft) of overburden in 10,000 years. Erosional processes are not expected to affect waste containment and isolation.

Table 2-7. Summary of Environmental Assessment Findings for Erosion (DOE, 1986) (continued)

Condition	DOE Finding
FAVORABLE CONDITIONS (continued)	
3. Site conditions such that waste exhumation would not be expected to occur during the first one million years after repository closure.	The evidence indicates that this favorable condition is present at Yucca Mountain: a waste repository in Yucca Mountain would not be exhumed during the first one million years at the fastest credible erosion rate.
POTENTIALLY ADVERSE CONDITIONS	
1. A geologic setting that shows evidence of extreme erosion during the Quaternary Period.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: there is no observed evidence of extreme stream incision rates during the past 300,000 years; little change has been observed in Quaternary erosional processes.
2. A geologic setting where the nature and rates of geomorphic processes that have been operating during the Quaternary Period could, during the first 10,000 years after closure, adversely affect the ability of the geologic repository to isolate the waste.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: no credible geomorphic process has been identiifed that could be expected to adversely affect the isolation capabilities of the proposed site in the next 10,000 years.

of more than 190 m between the repository and the water table beneath, which minimizes the future likelihood of submerging the repository and maximizes the advantage of long flow paths in the unsaturated rocks.

2.3.5.3.2 Review of Erosion Information Obtained since Environmental Assessment

2.3.5.3.2.1 Qualifying Condition

Since the EA was published, new data and interpretations of the geomorphic stability of the Yucca Mountain area have been completed. A regional study by Huber (1988) analyzes the late Cenozoic evolution of the upper Amargosa River drainage area. The basic regional drainage pattern was established soon after collapse of the Timber Mountain caldera and has changed little during the last 11 million years. Huber (1988) notes that a change in alluvial regimen is indicated by the end of alluvial-fan construction and the formation of incised washes through the process of fan-head erosion. Huber (1988) prefers a climatic cause (as opposed to a tectonic cause) for the alluvial-regimen change because of the apparent synchroneity of the system-wide change in the entire Amargosa drainage. He suggests that the climatic change may be the increasing aridity proposed for the Yucca Mountain region by Winograd and Szabo (1986) caused by the rise of the Sierra Nevada and the Transverse ranges. Huber (1988) states that Fortymile Wash has apparently reached a state of near-equilibrium, with little aggradation or bedrock degradation at present. This would include the ephemeral stream channels on the east flank of Yucca Mountain. Such a system-wide state of approximate long-term equilibrium in the Fortymile drainage system would argue against episodic pulses of erosion incising the stream channels on Yucca Mountain.

Huber's (1988) observations apply principally to channels eroded into the consolidated Tertiary volcanic rocks. There is evidence, however, of aggradation and downcutting in the alluvium within the bedrock channels. Alluvial terraces within the reach of Fortymile Wash, which is cut into the alluvium of western Jackass Flats, indicate that aggradation and downcutting have occurred at least four times since the middle Pleistocene (Taylor, 1986). Remnants of debris flows in Fortymile Canyon above Jackass Flats and in tributary channels at Yucca Mountain also show the episodic mobility of unconsolidated sediments within the channels (DOE, 1991c). Nonetheless, the resistant bedrock channels themselves and, more importantly, the bounding hillslopes show no evidence of high rates of incision.

Another indication of low erosion rates in the Yucca Mountain vicinity is provided by the Lathrop Wells cinder cone. Wells et al. (1990) document that the Lathrop Wells cinder cone has undergone little erosional modification. They state "the Lathrop Wells cone has the maximum cone slope, apparently no apron development and shows no erosional modification of the cone flanks and crater" and "very shallow discontinuous rills occur on the southwestern cone flank and within the crater, whereas the older cones of the Crater Flat area display deep gullies with inset fills, integrated channel networks, and aprons with well-developed soils." The age of the Lathrop Wells volcanic deposits is the subject of current debate. On the basis of the geomorphic evidence and comparison of the cone with others in the Cima volcanic field, the Lathrop Wells cone has been estimated as being less than 20,000 years old (Wells et al., 1990 and Crowe et al., 1988a). Recent studies, however, have indicated that the cone may not have been formed by polycyclic eruptions (Champion, 1991) and may be 130,000 years old (Turrin and Champion, 1991). Whether the cone is less than 20,000 years old or is approximately 130,000 years old, the minor amount of degradation that it has undergone accentuates how minor erosion is in the Yucca Mountain area.

Evidence of local hillslope stability at Yucca Mountain and the southwestern Nevada Test Site is provided by Whitney and Harrington (1988 and in preparation). Darkly varnished, colluvial deposits of large, angular boulders form linear stripes perpendicular to contour at Yucca Mountain, Skull Mountain, and Little Skull Mountain. The linear form and the lens-shaped cross section of these deposits suggest that they fill paleo-channels. Modern channels often incise the bedrock on one or both sides of a deposit with the deposit acting as a drainage divide. Dating of desert varnish on these deposits by the cation-ratio method provides estimated minimum ages of 170,000 and 760,000 for different boulder deposits at Yucca Mountain. This indicates that the deposits have been stable for long periods and that the minor amount of erosion on the stream channels between the deposits (less than 2.5 m) indicates hillslope erosion rates on the order of less than 2 cm per thousand (Whitney and Harrington, in preparation).

The accuracy of the cation-ratio dating method has been questioned recently by Bierman and Gillespie (1991) because of an overlap of barium and titanium in the energy dispersive spectrum analyzed by some methods. However, Bierman and Gillespie (1991) consider the method (SEM-EDAX) used by Whitney and Harrington (in preparation) to be reliable. Whitney and Harrington (in preparation) have incorporated consideration of the barium-titanium overlap both by their analytical method and by calibrating with radiometrically dated basalts in Crater Flat, which contain barium concentrations in their varnish that are similar to those of the Yucca Mountain colluvial boulders. Harrington et al. (1991) provide a detailed discussion of the need for decomposing barium and titanium peaks in analyses of the barium-rich varnishes of southern Nevada.

Whitney and Harrington (in preparation) also used the thermoluminescence method to date the fine-grained, eolian silt trapped in the colluvial boulder deposit. At Yucca Mountain the samples were dated as 3,900 ± 550 years at a depth of 12 to 18 cm; 11,240 ± 1,370 years at a depth of 30 to 35 cm; and 9,940 ± 1,030 years at a depth of 55 to 60 cm. These dates indicate a stability of the colluvial boulder deposits for the last 10,000 years. Thus, even without the cation-ratio dates, hillslope erosion can be seen to be less than one meter in 10,000 years at Yucca Mountain and probably much less when the cation-ratio dates are considered.

The findings just described indicate that low average rates of erosion at the Lathrop Wells cone and the resistant hillslopes of Yucca Mountain have prevailed during a significant part of the late Quaternary, including periods of climate extremes that are unlikely to be exceeded during the next 10,000 years. Although short-term erosion rates may have substantially exceeded the average, the total incision of resistant hillslopes through a time period comparable to and probably far exceeding the isolation period is minor when compared with the proposed depth of waste emplacement in Yucca Mountain.

The NRC commented on the Consultation Draft of the Yucca Mountain Site Characterization Plan (SCP-CD) (DOE, 1988c) and the Site Characterization Plan (SCP) (DOE, 1988a) regarding the issue of erosion at Yucca Mountain based upon Purcell (1986) work commissioned by the NRC since the EA was published. Several calculations are performed in Purcell (1986) in which erosion rates, measured in millimeters per year, are extrapolated to 10,000 years. The calculated estimates include an error in unit conversion that results in estimates that are an order of magnitude too great. This is evident on page 12 of Purcell (1986) where the text states, with regard to hillslope erosion, that "estimates ranging from 2 to 8.2 mm per year which converts to 200 to 820 m per 10,000 years are possible." The correct conversion should result in estimates of 20 to 82 m per 10,000 years. Also, on page 13, the text states, regarding scarp retreat, that "estimates based on Table 6 could range as high as 20 to 60 m per 10,000 years." The correct conversion of the values from Table 6 (0.2 to 0.6 mm per year) should result in extrapolated estimates of 2 to 6 m per 10,000 years. These errors were corrected in a revision to the original Purcell report that was prepared after January 1988 because a later report (Purcell, 1988) cited Purcell (1986) and quoted the same calculational errors. Because the report was not revised until sometime after January 1988, it is unclear why the final report is still dated 1986.

Nevertheless, it must also be noted that even these corrected estimates are extremely high overestimates for several reasons. The corrected 20 to 82 m per 10,000 years estimate of hillslope erosion is extrapolated from a range of values of 2.0 to 8.2 mm per year given in Table 5 of Purcell (1986, Revised). These values are for a semiarid region. It has long been recognized that sediment-yield rates (a measure of erosion rates) are higher in a semiarid region than in any other climatic regime (Langbien and Schumm, 1958 and Schumm, 1963). Sediment-yield rates are at a maximum at about 10 to 14 inches of precipitation, with sediment-yield values decreasing sharply on both sides of this precipitation maxima. For lower precipitation, the decrease is caused by a deficiency of runoff; and, in the case of greater precipitation, the decrease is caused by increased density of vegetation (Langbien and Schumm, 1958). Langbien and Schumm (1958) used measured runoff values to derive "effective precipitation" (i.e., by their definition, the amount of precipitation required to produce the known amount of runoff) and note that "more precipitation is required for a given runoff in a warm climate than in a cool climate." The very warm climate present at Yucca Mountain would lower the effectiveness of the precipitation to provide runoff. Yucca Mountain is in a warm, arid region, and thus the sediment yield and erosion rates will be less than in a semiarid region.

Purcell (1986, revised) cites Schumm and Chorley (1983) for the data in his Table 5. A review of Schumm and Chorley (1983) shows that they derived their version of these data from Young (1972). The data tabulated in Young (1972) provide values for "observed rates of surface wash." Surface wash is defined by Young (1972) as the downslope transport of regolith material across ground surface, through the agency of moving water. Thus, this value is for the removal of unconsolidated surficial material. Young (1972) cites Leopold et al. (1966) for these data. Leopold et al. (1966) indicate that these values are derived from measurements of slope wash in Arroyo de los Frijoles, New Mexico, where the material being eroded is unconsolidated, alluvial silty sand.

Yucca Mountain is composed of erosionally resistant, welded ash-flow tuff and not regolith or unconsolidated silty sand. Rather than indicating that erosion is a concern, this estimate in Purcell (1986, revised) provides assurance that hillslope erosion will not be capable of uncovering the proposed repository, even under the worst-case scenario conditions (i.e., the climate changes to semiarid and the mountain, through some unexplained mechanism, becomes regolith or unconsolidated silty sand).

The revised values estimated by Purcell (1986, revised) for escarpment retreat, which extrapolate to 2 to 6 m per 10,000 years, appear to be sufficiently insignificant that they will not impact on waste isolation. This is especially true because they are based on extrapolation of erosion values for sedimentary rock that is generally less erosion-resistant than welded tuff and are for a semiarid/arid climate. These data in Purcell (1986, Revised) are again taken from Schumm and Chorley (1983), who reported the data from Young (1972). Young (1972) indicates that these values are estimates for cliff recession for sandstones in the Grand Canyon. Young (1972) provides estimates of time required for 1 m of cliff recession for hard rocks and indicates that the value for the semiarid environment is 1,000 to 10,000 years, while the value for the arid environment is ten million years.

Purcell (1986, Revised) corrects the calculational errors, but none of the conclusions in Purcell (1986) were changed in Purcell (1986, Revised), although those conclusions are inconsistent with the corrected values for the calculations. The incorrect set of calculations indicated that the potential existed for erosion to uncover the repository in less than 10,000 years, whereas the corrected calculations indicate that, even given the unstated assumptions (i.e., Yucca Mountain is composed of unconsolidated alluvium in a semiarid region), the repository would not be breached.

2.3.5.3.2.2 Disqualifying Condition

Since the EA was published, a discrepancy at some locations has been noted (Rautman, 1985; Hunter, 1989; Blejwas, 1991) with regard to the elevation of the contact between the lithophysae-rich and underlying lithophysae-poor units of the Topopah Spring welded tuff, as described by Ortiz et al. (1985). The lower (lithophysae-poor) unit is the proposed host rock for the repository. In May of 1991, an evaluation of core was performed to reevaluate the location of this contact in five boreholes (Peck et al., 1991). The evaluation concluded that the contact is easily recognizable in core samples and can be correlated across the proposed repository block from north to south and from east to west. In borehole UE25-a#1, the depth of the contact is at 198 m (650 ft), and it is deeper in all other boreholes. UE25-a#1 is located outside of the proposed repository block, and the proposed repository is planned to be located tens of meters below the contact. This indicates that the underground facility can be situated more than 200 m below the ground surface directly overhead. Figure 2-1 shows the overburden thickness above the current design depth of the repository.

2.3.5.3.3 Conclusions and Recommendations for Future Erosion Activities

<u>Qualifying Condition</u>

Several lines of evidence regarding erosion in the Yucca Mountain region have been examined. From the regional perspective of geomorphic stability, all studies indicate that erosion is minor at Yucca Mountain. Estimates of erosion during periods of 10,000 years or longer are summarized in Table 2-8.

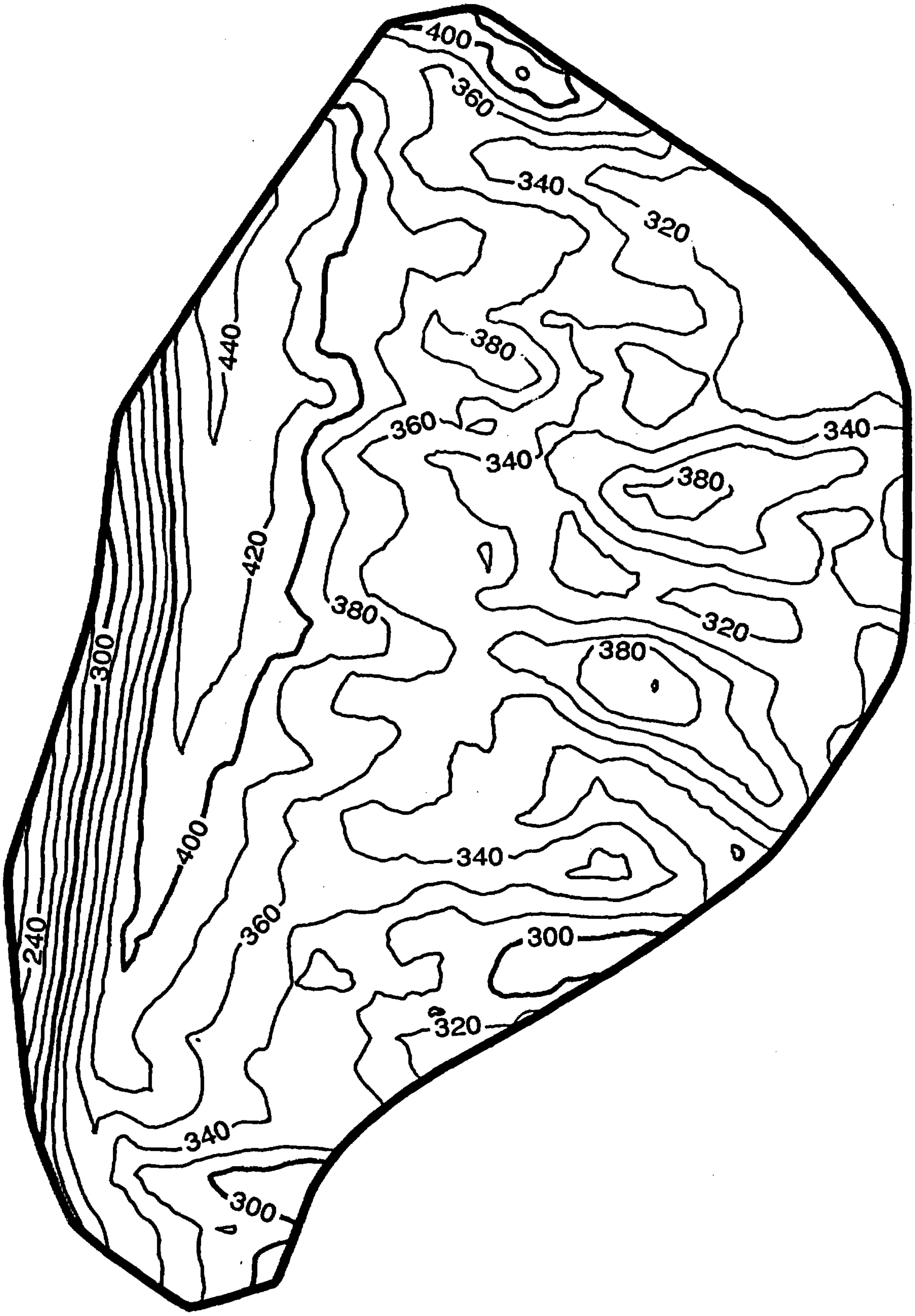


Figure 2-1. Thickness between surface of Yucca Mountain and repository horizon, in meters.

Table 2-8. Summary of Erosion Estimates During Periods of 10,000 Years or Longer

Study	Material	Erosion Rate
Champion (1991) and Turrin and Champion (1991)	Lathrop Wells Volcanic Cone	Negligible erosion for 130,000 years
Wells et al. (1990) and Crowe et al. (1988)	Lathrop Wells Volcanic Cone	Negligible erosion for 20,000 years
Purcell (1986, revised)	Unconsolidated, alluvial silty sand	8.2-20 m/10,000 years
Whitney and Harrington (1988, and in preparation)	Yucca Mountain, softer tuffs	<0.2 m/10,000 years
Whitney and Harrington (in preparation)	Yucca Mountain, resistant tuff hillslopes	<0.1 m/10,000 years

The consensus of the Core Team is that the evidence provides strong assurance that the site meets the qualifying condition and is likely to continue to meet the qualifying condition (Level 4).

Disqualifying Condition

Recent findings confirm earlier judgments that the proposed repository can be sited at Yucca Mountain so that the overburden thickness is greater than 200 m at all locations directly over the proposed underground facility. The consensus of the Core Team conducting this evaluation is that the site is not disqualified on the basis of existing evidence and is not likely to be disqualified (Level 2).

Discussion

For the purpose of this guideline alone, the existing information, even considering residual uncertainties in experimental dating techniques, is adequate to support the higher-level suitability findings. Additional studies of erosion, described in Section 8.3.1.6 of the SCP, could be useful in the characterization of Quaternary climates and tectonism, and to confirm current estimates of the effects of predicted climates on short-term erosion rates.

2.3.6 DISSOLUTION TECHNICAL GUIDELINE

2.3.6.1. Statement of Qualifying and Disqualifying Conditions

Qualifying Condition [10 CFR 960.4-2-6(a)]: "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 evidence of dissolution within that setting during the Quaternary Period including the locations and characteristics of dissolution fronts or other dissolution features, if identified."

Disqualifying Condition [10 CFR 960.4-2-6(d)]: "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."

2.3.6.2 Discussion and Approach for Dissolution Evaluation

The objective of this guideline on dissolution is to ensure that dissolution processes will not adversely affect the waste-isolation capabilities of a repository site. The principal concern is that the dissolution of the host rock might create new pathways for radionuclide migration to the surrounding geohydrologic system.

Within the preamble of 10 CFR Part 960, it is stated: "The sites with salt as a 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 statement suggests that this guideline was intended for consideration in evaluating salt sites; however, nowhere in Part 960 does it mention that this guideline was for salt sites exclusively. Therefore, every site, regardless of rock type, must be evaluated in terms of the Dissolution Guideline.

To carry out such an evaluation, the terms of this guideline should be precisely defined. Semantically, there may be some confusion concerning the difference between "dissolution" and mineral alteration. For this evaluation, the definition of dissolution shall be as follows: "A chemical process by which minerals and rock material pass into solution by a separation and dispersion of their component parts." Dissolution products, therefore, shall be understood to mean materials that are dissolved in ground water and transported away as species in the ground water.

Mineral alteration occurs when chemical-driving forces favor a new mineral assemblage over the current mineral assemblage because of changes in environmental conditions (e.g., pressure, temperature, and other chemical changes). Ground water usually participates in mineral alteration by providing the fluxing medium. The amounts of material in the ground water associated with mineral alteration, however, are exceedingly small compared with dissolution of the salt halite (NaCl) or other evaporite minerals such as gypsum ($CaSO_4 \cdot 2H_2O$).

Dissolution and mineral alteration may also be distinguished on the basis of the change in volume of the solids associated with both processes. During the process of dissolution, the volume of the solid being dissolved is reduced up to the point of total removal. This is why the Potentially Adverse Condition of this guideline lists evidence of dissolution in terms of reduced volumes of materials, i.e. breccia pipes, dissolution cavities, significant volumetric reduction, and structural collapse. On the other hand, mineral alteration involving ground water does not lead to significant volume reduction. As a general rule, when minerals are altered as a result of interactions with ground water, there is an increase in the molar volumes of the new minerals relative to the reactant minerals. This increase in molar volumes can and does lead to the infilling of cracks and fractures within rocks, which also leads to a decrease in their permeabilities.

2.3.6.3 Current Status of Dissolution Information

2.3.6.3.1 Summary of Environmental Assessment Findings for Dissolution

The evaluation of the Dissolution Guideline in the Environmental Assessment (EA) (1986) addressed the favorable condition, potentially adverse condition, qualifying condition and disqualifying condition. The data that support these evaluations are listed in the EA and consist mainly of reports on the mineralogical and petrological characteristics of the volcanic rocks at Yucca Mountain. On the basis of these data, the evaluations concluded that no dissolution features existed within both the host rock and other volcanic rocks of Yucca Mountain. The evaluations state that the mineralogy of the mountain is "simple;" more than 98 percent consists of quartz cristobalite and feldspar. The remainder is composed of other silicate and oxide minerals, all of which do not dissolve in the nearly neutral, largely oxidizing ground waters of the Yucca Mountain region. The conclusions reached were as follows:

1. There is no evidence that the host rock at Yucca Mountain was subject to any dissolution during the Quaternary Period, and, therefore, the evidence indicates that the dissolution favorable condition exists at Yucca Mountain.

2. There is no evidence of significant dissolution that would provide hydraulic interconnections between the host rock and any immediately surrounding geohydrologic unit, and, therefore, the potentially adverse condition is not present at Yucca Mountain.

3. Based on the geologic record, no dissolution is expected during the first 10,000 years after repository closure, and, therefore, the evidence supports a finding that the site is not disqualified on the basis of that evidence and is not likely to be disqualified (Level 2).

4. The minerals that compose the rock in and around the Yucca Mountain site are considered insoluble, and significant dissolution is not a credible process leading to radionuclide releases greater than those allowable under the requirements specified in 10 CFR 960.4-1; therefore, the evidence supports a finding that the site meets the

qualifying condition and is likely to continue to meet the qualifying condition for Postclosure Dissolution (Level 4).

One area of confusion associated with the EA evaluations was the discussion of hydrothermal alterations in the deeper rocks beneath the repository horizon. The evaluation stated that there is no evidence that hydrothermal alteration leads to dissolution, possibly implying that this process may, under some conditions, actually lead to dissolution.

2.3.6.3.2 Review of Dissolution Information Acquired since the Environmental Assessment

New information since the EA (approximately 1984) includes summary reports of all relevant mineralogic and petrologic data on the volcanic rocks of Yucca Mountain (Broxton et al., 1987; Bish and Chipera, 1989; Byers and Moore, 1987; Carlos, 1987; Carlos et al., 1991). Again no evidence was discovered concerning dissolution features of the volcanic rocks at Yucca Mountain.

In 1983, a deep hole (UE-25p #1) was drilled immediately east of the Yucca Mountain site. This hole penetrated the volcanic strata and entered the underlying Paleozoic rocks. Several reports on this borehole discuss the characterization of the underlying strata, including the carbonates in the Paleozoic formations (Muller and Kibler, 1984; Carr et al., 1986; Chipera and Bish, 1988). The qualifying condition requires that "any subsurface rock dissolution will not be likely to lead to radionuclide releases" (underlining added). The only limit to the depth at which dissolution features should be considered is controlled by what would be defined as likely pathways for radionuclide releases that could be greater than those specified in 40 CFR Part 191. The most likely path to the accessible environment includes a segment in the uppermost aquifer that is located in the volcanic strata. The carbonate aquifers are not expected to constitute paths because of the intervening aquitard, and the higher hydraulic head of the waters in these aquifers, i.e., breaches of the intervening aquitards result in flow from the aquifers in the Paleozoic formations to the aquifer in the volcanic strata. The carbonate aquifers and dissolution processes that may or may not proceed within them are not issues of concern with regard to this guideline.

2.3.6.4 Conclusions and Recommendations for Future Dissolution Activities

The consensus of the Core Team is that current information continues to support the higher-level findings presented in the EA for both the disqualifying (Level 2) and the qualifying (Level 4) conditions for the Dissolution Guideline.

No further activities are recommended to support evaluations of this guideline.

2.3.7 POSTCLOSURE TECTONICS TECHNICAL GUIDELINE

2.3.7.1 Statement and Discussion of Qualifying and Disqualifying Conditions

Qualifying Condition [10 CFR 960.4-2-7(a)]: "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."

Disqualifying Condition [10 CFR 960.4-2-7(d)]: "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."

Discussion. This technical guideline addresses the potential for a loss of waste isolation resulting from tectonic processes during the required isolation period of 10,000 years following closure of a repository. The qualifying condition requires a demonstration that the Postclosure System Guideline will be met, considering the probabilities and effects of future tectonic processes. The statement of the qualifying condition is followed by the guidance, "In predicting the likelihood of potentially disruptive tectonic events or processes, 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." In the Supplementary Information ("Statement of Basis and Purpose," Section IV.B.3) of 10 CFR Part 960, "this guideline requires that the tectonic history of a site be carefully examined and the results of this examination be used to predict the likelihood of potentially disruptive tectonic processes or events." Further guidance in Section IV.B.3 defines tectonic processes to include igneous activity, uplift, subsidence, folding, and faulting.

The wording, "will not be likely to lead to radionuclide releases," in the qualifying condition implies that the evaluation is to be in terms of the effects of tectonic processes on incremental releases predicted by probabilistic, system performance-assessment calculations. However, the emphasis of the guidance stated above and of this present evaluation is on the nature and probabilities of disruptive tectonic processes and on the separate effects of these processes on repository performance. Final resolution of the technical issues covered by the qualifying condition may involve system performance calculations, as are discussed in the consideration of the Postclosure System Guideline found in Section 2.4 of this evaluation. However, some processes may be found to have no credible likelihood of occurrence by evaluating the geologic record alone, or they may be found not to affect waste containment or isolation significantly on the basis of process or subsystem models.

The disqualifying condition is somewhat narrower than the qualifying condition in its considerations. First, the disqualifying condition is explicit that the judgment is to be based on the geologic record during the Quaternary Period. Second, it restricts the consideration to "fault movement or other ground motion." Last, it imposes the condition, "expected," on the fault movement or other ground motion, allowing resolution to be based on a demonstration that a continuation of processes acting during the Quaternary Period would be unlikely to result in a loss of isolation.

Critical judgment about whether the site is disqualified can be guided by sequential consideration of the following two questions. One, based on the Quaternary record, is it expected that fault movement will occur within the repository or that ground motion within the repository from outside seismogenic sources will be so severe as to cause a loss of containment within the engineered barrier system (EBS)? Two, if fault movement or ground motion causes a loss of containment, is it likely to result in a loss of waste isolation, i.e., releases of radionuclides to the accessible environment exceeding those allowed by the regulations? A negative answer to the first question would provide the basis for a determination that the site is not disqualified under this condition. An affirmative answer to the first question, however, would cause deferral of the determination until the effect on waste isolation, which is addressed in the second question, can be evaluated by system performance calculations.

2.3.7.2 Approach for Postclosure Tectonics Evaluation

2.3.7.2.1 Identification and Basis for Postclosure Tectonics Technical Issues

The considerations for the disqualifying condition are embedded in those for the qualifying condition. Therefore, the information requirements for evaluating the disqualifying condition are a subset of those for evaluating the qualifying condition. Further discussion of the disqualifying condition is deferred to Section 2.3.7.3.3.

The technical issues applicable to evaluating the site with respect to qualification under this guideline are the probabilities and credible effects of tectonic processes that might lead to radionuclide releases exceeding those specified in § 960.4-1, either by a loss of containment within the engineered barrier system (EBS) or by a loss of isolation because of gaseous, aqueous, or direct releases to the accessible environment. The issues that encompass these considerations are stated and discussed in the following paragraphs. In addition to those derived from the guidance in 10 CFR Part 960, the specific concerns (tectonic processes, events, and disruptive effects) within the technical issues reflect the increased understanding that has resulted from several influences since the development of 10 CFR Part 960 and the Environmental Assessment (EA) (DOE, 1986). The first set of influences was the preparation of the Yucca Mountain Site Characterization Plan (SCP) and the subsequent review of and response to the comments of other organizations and individuals on the consultation-draft and final versions of the SCP. Of particular note is the inclusion in the final SCP (DOE, 1988a) of detailed tables defining the current representations and alternative hypotheses regarding the nature and rates of tectonic processes, as well as the uncertainties and importance associated with the current and alternative representations. The second set of influences includes technical exchanges with the U.S. Nuclear Regulatory Commission, the State of Nevada, the Nuclear Waste Technical Review Board, and other organizations and panels. The oral and written comments and questions from these groups have helped to focus the broad wording of the guideline on the site-specific issues of greatest importance for the Yucca Mountain site. The third set of influences comprises written technical positions taken by individual scientists regarding tectonic processes that, in the authors' opinions, are likely to occur at the site and render it unsuitable. The most widely known and discussed of these is a hypothesis regarding transient tectonic control of the hydrologic system, proposed by Szymanski (1989) and first released in draft form in November 1987. Finally, in a recent report, Mattson et al. (1991) systematically examined the technical issues, or potential concerns, with respect to the waste-isolation capabilities of the Yucca Mountain site and tentatively ranked them in order of importance.

The technical issues raised during this evaluation of early site suitability include:

- <u>Technical Issue 1</u>

  Is it reasonably likely that faulting or ground motion will damage the EBS and, if so, that the damage, coupled with changes of water flux through the repository, will cause releases of radionuclides from the EBS that exceed the limits allowable under 10 CFR 960.4-1?

This issue is similar to the disqualifying condition for the Postclosure Tectonics Guideline, except that (a) it addresses the possible loss of containment of radionuclides within the EBS rather than releases to the accessible environment and (b) it asks whether the loss of containment is "reasonably likely," rather than "expected." In addition to addressing the containment consideration within the Postclosure System Guideline, the evaluation of this issue also serves to provide a radionuclide source term for evaluations of Issues 2 and 3.

Specific concerns within this issue include (a) the characteristics and effects on the EBS of ground motion from faulting within or outside the repository boundary; (b) fault-zone orientation, width, and displacement for faulting within the repository boundary and the effects on EBS integrity; and (c) locally increased concentration of flux into the repository, including that which results either from water ponding at the surface or from perched water in the subsurface, and leading to accelerated rates of EBS degradation.

- <u>Technical Issue 2</u>

  Will damage to the EBS from faulting or ground motion result in releases of radionuclides to the accessible environment in the gaseous phase at rates that exceed those allowable under 10 CFR 960.4-1?

The issue of gaseous-phase releases has arisen since the EA was prepared and was tentatively assigned the greatest importance of the potential concerns evaluated by Mattson et al. (1991). Sudden rupture of waste packages either by fault dislocation or by impact with emplacement-hole walls during ground shaking might provide the extreme case for high-rate release of gases.

Specific concerns within this issue, in addition to those for Issue 1, include (a) the increase in rates of gaseous releases from ruptured or rapidly degraded waste packages and (b) the mobility of gaseous radionuclides to the surface through the rocks above the repository, including along a pathway resulting from new or renewed faulting.

- Technical Issue 3

  Will changes to the hydrologic system resulting from tectonic processes, including igneous activity, cause releases of radionuclides to the accessible environment at rates that exceed those allowable under 10 CFR 960.4-1?

This issue encompasses most of the considerations that can be readily derived from the guidance and explanations regarding this guideline in 10 CFR Part 960, including the hydrologic effects of faulting, folding, vertical movements of the earth's crust, and both intrusive and extrusive igneous activity. The transient effects of crustal strain and hydrothermal activity initiated by faulting, as proposed by Szymanski (1989), are also within the scope of this issue.

Specific concerns within this issue, in addition to those for Issue 1, include (a) the development of rapid flow paths through the unsaturated zone, either by perching of water within or below the repository or through a new or renewed fault zone; (b) the development of rapid flow paths through the saturated zone along a new or renewed fault zone; (c) an interruption of existing flow paths by faulting with a consequent rise of the water table beneath the repository; (d) the development of new flow paths toward the repository from areas of higher water table with a consequent rise of the water table beneath the repository; (e) an igneous intrusion causing interruption of existing flow paths or hydrothermal circulation with consequent rises of the water table beneath the repository; (f) a coseismic release of extensional strain between fault zones, resulting in a reduction of fracture porosity with a consequent rise of the water table beneath the repository, which is also maintained for a long period of time because of reduced hydraulic conductivity; (g) a coseismic rise of ground water along a fault zone (seismic pumping); (h) a hydrothermal rise of ground water along a new or renewed fault zone; and (i) adverse changes to the regional flow system resulting from uplift, subsidence, tilting, or folding.

The concerns (c through f) that address a rise of the water table beneath the repository have significance within three classes of increasing consequence. First, water-table rises up to about 200 m would shorten flow paths in the unsaturated zone, increasing rates of flow to the accessible environment. Second, water-table rises of about 200 to 400 m would submerge the repository in addition to greatly increasing rates of flow. Last and most severe, water-table rises greater than about 400 m would allow discharge of ground water within the controlled area, though not necessarily of water that circulated through the repository.

- Technical Issue 4

  Will direct releases of radionuclides to the land surface by volcanic eruptions exceed the limits allowable under 10 CFR 960.4-1?

Mode of release rather than the tectonic process distinguishes this issue from the effects of igneous processes considered in Issue 3. Volcanism during the Quaternary Period is evident from the presence of basalt cinder cones in Crater Flat, which is adjacent to Yucca Mountain. This has resulted in the perception by many individuals that the potential for direct releases of radionuclides to the land surface by volcanic disruption of a repository at Yucca Mountain is highly significant. There are no specific concerns subdividing this issue.

2.3.7.2.2 Information Required to Resolve Postclosure Tectonics Issues

To some extent, the technical issues are interrelated. For example, Issue 1 (Releases from the EBS) might be resolved if faulting or severe ground motion is shown to be very unlikely to occur within the repository. Nonetheless, the analysis is necessary to provide the source term in order to evaluate the effects of disruptive tectonism on gaseous and aqueous releases to the accessible environment (Issues 2 and 3, respectively). Similarly, the tectonic processes addressed in all of the issues share a common origin; the issues differ as to the location or mode of release. To resolve the set of four issues, a sequence of actions to develop information and analyses can be applied, although not all analyses will apply to all technical issues. These analyses are described below in terms of the development of models, but the term is used in the broadest sense--from conceptual understanding to predictive numerical models, whether probabilistic or deterministic, and from process models to site-specific subsystem or total-system models. It must be recognized that predictions resulting from the sequential consideration of these models incorporate the uncertainties that are inherent in geologic prediction. There is uncertainty not only as to the effects of given tectonic processes, but also as to what processes will be acting, and at what rates, in the future. Therefore, reasoned judgment plays an important role in evaluating this guideline, as it does in all aspects of site evaluation.

(1) Tectonic models for the site area. The framework for evaluating all of the technical issues is a set of credible alternative models. Resolution of the technical issues requires forecasting probabilistically the effects of tectonic processes, including:

- Locations and orientations of new or renewed faulting at or near the surface
- Subsurface geometry of the structural system
- Fault displacement (magnitude and direction of slip)
- Width of fault zones, including secondary or distributed faulting
- Earthquake recurrence intervals, magnitude, and ground-motion characteristics
- Magnitude and spatial distribution of stress changes
- Changes of the hydrothermal regime

- The locations and characteristics of volcanism
- Locations, magnitudes, and rates of uplift, subsidence, or folding

To address the specific concerns within the technical issues, derivative models are needed to evaluate individual attributes of faulting and igneous processes on a probabilistic basis. However, to forecast the above effects credibly, such models should be derived from and consistent with the overall tectonic model or models that best explain the composite set of tectonic features in the Quaternary record, including the current seismic, stress, and geothermal regimes.

A set of observational, measured, and calculated data is required to support the development and evaluation of alternative tectonic models. Field mapping of the occurrence and geometry of faults and structural features of the stratigraphic system, supplemented by subsurface data from drill holes and geophysical surveys, provide the fundamental geometry for interpreting structural history and, thus, an understanding of the tectonic processes acting in the region and at the site. Equally important to this understanding is the chronology of structural and igneous events, which depends on relative and radiometric dating of rocks, soils, and secondary deposits. The geochemistry and volumetric rate of magmatism are fundamental to extrapolating the possible future significance of igneous processes. The last 4 million years of this chronology, i.e., the late Pliocene and Quaternary, are the most directly relevant to understanding the nature and rates of tectonic processes that may affect the site. However, the geologic record of Cenozoic extension, principally mid-Miocene (about 15 million years ago) and later, provides an essential context for interpreting the evolutionary nature of tectonism in this area of the southern Great Basin. Similarly, determinations of the current state of in situ stress, seismicity, and thermal structure provide the linkage from the Quaternary history into the near geologic future, such as 10,000 years.

There is disagreement as to the tectonic significance of some geologic features in the Yucca Mountain area, such as the calcite-silica infillings of faults and fractures cited by Szymanski (1989) in support of his coupled tectonic-hydrothermal-hydrologic conceptual model. Therefore, a subset within the broader context of tectonic models is an understanding, or conceptual model, of Quaternary processes that have produced features interpreted by some to record tectonic events. In addition to the chronology of Quaternary history discussed previously, this conceptual model depends upon information being collected for paleoclimatologic and paleohydrologic studies. The information includes isotopic (stable and radiogenic) analyses of water and geologic deposits; the sedimentary, mineralogic, and paleontologic characteristics of the geologic deposits; and models (e.g., pedogenic processes) that are alternatives to tectonic origins for the deposits or other features.

(2) Ground-motion model. To estimate the postclosure effects of earthquakes, the hazard from ground shaking at the proposed repository depth must be assessed. Models for expected ground motion during the postclosure period are available, but additional calculations will be needed as data, viable tectonic models, and/or analysis techniques change (See Section 3.3.3.4.4, Issue #1: Maximum Ground Motion). Instrumental measurements of

subsurface ground motion are sparse, as are reported observations of the effects of ground motion on underground openings. Thus, additional data will be needed to improve the reliability of characterizing ground motion at the repository depth compared with predicted ground motion at the surface. Because of various uncertainties relating to future tectonic activity, probabilistic estimates of ground motion (See Section 3.3.3.4.4, for example) are inherently difficult to validate for the long postclosure period of concern. Deterministic analyses will also be conducted to provide companion guidance in evaluating the exposure of the repository to future ground motions associated with the earthquake-generating framework of the Yucca Mountain region.

Data to support ground-motion models are required from both local and regional (Great Basin) earthquake-monitoring networks, the latter to guide adjustment of modern ground-motion predictions to credible values in the evolving tectonic setting. The instrumental record is limited, however, and must be extended by estimates of paleoseismicity from field studies of faults in the vicinity of Yucca Mountain and at sites that are possible analogs for future tectonism at Yucca Mountain.

Strong-motion estimates close to faults that are reasonable analogs for faults near Yucca Mountain are also needed because of the small likelihood of direct observations at the site during site characterization. Observations, mainly noninstrumental, of ground motion and its effects in underground structures need to be assembled and systematically analyzed. Important data are also provided by instrumental observations, both at the surface and at depth, of ground motion from underground nuclear explosions at the Nevada Test Site.

Deterministic calculations, probabilistically predicted ground motion guided in part by information from tectonically analogous settings, and observations of subsurface effects must be considered together to reach defensible judgments of the hazard to waste containment and isolation. If the hazard is shown to be of credible consequence, system performance assessments can appropriately be expressed probabilistically, accounting for associated uncertainties.

(3) EBS damage and degradation models. Predictions of damage to the EBS from ground motion and fault rupture are required for the evaluation of Issue 1 and, therefore, of Issues 2 and 3. Probable increases in the rates of degradation resulting from the tectonically induced contact of water with the damaged EBS should also be assessed for the estimated ranges of chemical and physical characteristics of water from credible sources.

Estimates of EBS damage and degradation should be developed from laboratory data and theoretical analyses based on credible fault displacement, ground motions, and hydrologic conditions. Applicable field data include observations of damage to underground structures during earthquakes and the characteristics of water that may be perched in the unsaturated zone and that occurs at various depths in the saturated zone.

The cumulative effect of ground motion from recurrent faulting within the next 10,000 years in the near field may be greater than the effect of single events and, therefore, requires evaluation. Similarly, estimates of

EBS damage should consider probabilistically the possibility of secondary faulting within the repository even though the primary fault is outside of the design perimeter. Paleoseismic investigations are important for extending the historical record for evaluating both recurrent and secondary faulting.

(4) Strain-response models. Process models to predict the magnitudes and durations of hydraulic effects of strain adjustments that accompany faulting are required to evaluate the significance of transient tectonic influence on the ground-water system.

Data acquired from the field include direct observations of faulting effects, including hydrologic changes, and geologic information that may help estimate past water-table altitudes and flow patterns. Models that are currently under development are based on elastic dislocation models for predicting ground motion. Data requirements to support the assumptions in strain-response models include fault configuration from tectonic models and the spatial distribution of geomechanical and hydraulic properties, particularly as they relate to the thickness of the crust that may be involved.

(5) Flow and transport models. A family of process and site-specific models is required to evaluate the effects of tectonism on waste containment and isolation, assuming that at least some of the initiating processes (specific concerns) are found to be sufficiently credible to warrant further analysis. The primary requirements for most of these models occur in the evaluations of the Postclosure Geohydrology and System Guidelines (Sections 2.3.1 and 2.4, respectively), where unsaturated-zone flow of gases and water and flow of water in saturated, fractured rocks are examined. The principal modifications to the site-specific models required for evaluation of the Postclosure Tectonics Guideline are (a) incorporation of hypothetical faults and intrusive rock masses, with ranges of credible hydraulic properties, and (b) adjustment of the hydrogeologic units to account for the addition (saturated zone) or deletion (unsaturated zone) of flow paths resulting from a rise of water-table altitude. Dipping strata and structural features indicate that three-dimensional models should be used for much of the analysis. Process or subsystem models of more limited scope should be used to evaluate thermal effects on ground-water flow and the effects of tectonism on flow through the repository. Finally, if ground-water flow is determined to be significantly affected by tectonic processes, evaluation of the guideline with respect to releases to the accessible environment should be made with transport models that incorporate retardation processes.

Data to support these models are principally those required for the Postclosure Geohydrology Guideline. Supplemental requirements include the geometries and hydraulic properties of hypothetical new or renewed faults and intrusive bodies, which are best acquired from observations and tests at the site and elsewhere and from geothermal information at and near Yucca Mountain.

(6) Probabilistic volcanic-release model. Although the tectonics models are important to understanding the locations and chronology of volcanism within a broader framework, substantial progress has been made in extending beyond the geologic data toward a probabilistic risk-assessment approach to

estimating volcanic releases of radionuclides (Crowe et al., 1982; Crowe, 1986, 1990).

The analysis of volcanic risk requires principally the locations, extruded magma volumes, and chronology of basaltic volcanism, including details of the eruptive history at individual volcanic centers. Refinement of probabilities based on random occurrences of volcanism requires the additional considerations of regional structural features, geophysical data, and the geochemical evolution of magmas.

2.3.7.2.3 General Approach to Postclosure Tectonics Guideline Resolution

Resolution of the four technical issues comprised by the guideline requires a demonstration (a) that each specific concern will not result in an unacceptable loss of waste isolation and (b) that the combined probabilistic releases, when added to those predicted in the absence of tectonic effects, will not cause the allowable limits to be exceeded. A specific concern may be dropped from consideration if it is shown that the probability of the initiating event is nil (<1 chance in 10,000 over 10,000 years) or if the credible intermediate effects (e.g., a water-table rise of 10 meters) are shown to be inconsequential.

The geologic record for the Quaternary Period and current indications, such as seismicity, should be considered within the context of credible tectonic models to evaluate the probability of initiating events such as faulting, volcanism, uplift, or folding. Those events that have occurred should be further evaluated in a probabilistic manner by considering the chronology of their occurrence.

Intermediate effects include those changes of tectonically undisturbed conditions and processes that would occur between the initiating event and the release of radionuclides to the accessible environment. In addition to an induced water-table rise, examples include perching of water in the unsaturated zone, rupture of waste packages by fault movement, or entrainment of waste packages in a rising magma. The significance of such effects would be evaluated in some instances by process and subsystem models or, in others, by defensible logical analyses.

For those concerns that remain credible after considering initiating events and intermediate effects, further analyses by subsystem modeling or system modeling of limited scope should be performed. Finally, those processes that still appear to be significant relative to the tectonically undisturbed case would be subject to system analyses that consider radionuclide transport and consequences of release.

2.3.7.3 Status of Current Postclosure Tectonics Information

2.3.7.3.1 Summary of Environmental Assessment Findings for Postclosure Tectonics

In the EA for the Yucca Mountain site (DOE, 1986), the DOE compiled the existing information that was applicable to evaluating the site with respect to the qualifying, disqualifying, favorable, and potentially adverse conditions specified in 10 CFR Part 960 and reached judgments (findings) as to the status of the site. Table 2-9 lists the conditions and summarizes of the DOE findings. The following paragraphs expand upon the bases for these judgments.

The DOE reached a lower-level finding (Level 1) that the evidence does not support a finding that the site is disqualified. The finding was based on the expectation that the largest earthquake in the vicinity of the site would occur from a 17-km rupture on the Bare Mountain Fault, producing a magnitude 6.8 earthquake about 14 km west of the site. The predicted surface ground motion at the site was 0.4g, with smaller motion and little effect at repository depth. The possibility of movement on smaller existing or new faults at the site was acknowledged with the recognition that some waste containers could be ruptured. But the consequence of container rupture was considered small because of the small flux of water in the unsaturated zone and the predicted long travel time (>10,000 years) to the accessible environment. Calculations indicated that the U.S. Environmental Protection Agency (EPA) limits on cumulative curies released to the accessible environment would not be violated for EBS containment times as short as 300 years and unsaturated-zone fluxes as much as 40 times the currently estimated upper bound of 0.5 mm per year.

Similarly, the DOE reached a lower-level finding (Level 3) that the evidence does not support a finding that the site is not likely to meet the qualifying condition. With respect to ground motion and faulting, the DOE's reasoning was the same as that for evaluating the disqualifying condition. In addition, the probability that basaltic volcanism might disrupt the repository during the 10,000-year isolation period was estimated to be about 1 chance in 10,000. For the isotopes with the largest expected releases in this scenario, plutonium-239 and plutonium-240, the releases were estimated as 23 curies each per 1,000 metric tons of heavy metal (MTHM), considerably less than the EPA limits of 100 curies per 1,000 MTHM and, for unlikely events (<0.1 over the 10,000-year period), of 1,000 curies per 1,000 MTHM.

The DOE selected the conservative position that the favorable condition is not present at Yucca Mountain because of the absence of probability values for most tectonic processes and events and because the upper bound on volcanic-event probabilities is larger than the value specified by this condition.

The DOE concluded that the first potentially adverse condition is present at Yucca Mountain because of evidence for both basaltic volcanism and recurrent faulting in the vicinity of the site during the Quaternary period.

The second potentially adverse condition was judged not to be present at Yucca Mountain. The evaluation supporting this position notes that Yucca Mountain is located between an area of moderate historical seismicity to the north and an area of lower seismicity to the south; historical seismic activity within 10 km of the site includes only two earthquakes of magnitude (M)>3 (3.6 and 3.4), and the peak historical acceleration at a location in Jackass Flats, 12 km east of Yucca Mountain has been estimated to have been less than 0.1g. Major historical earthquakes in the geologic setting include the following: 1872, M=8+, 150 km west of Yucca Mountain (Owens Valley,

Table 2-9. Summary of Environmental Assessment Findings for Postclosure Tectonics (DOE, 1986)

Condition	DOE Finding
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.	Existing information does not support the finding that the site is not likely to meet the qualifying condition (Level 3): potential tectonic events are not likely to cause radionuclide releases greater than allowable; low water flux and travel times greater than 10,000 years in the unsaturated zone are expected to prevent dissolution and transport of radionuclides.
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.	The evidence does not support a finding that the site is disqualified (Level 1). The nature and rates of fault movement or other ground motion are not likely to cause loss of waste isolation; low water flux and long ground-water travel times provide additional assurance of waste isolation.
FAVORABLE CONDITION	
The nature and rates of igneous activity and tectonic processes (such as uplift, subsidence, faulting, or folding), if any, operating within the geologic setting during the Quaternary Period would, if continued into the future, have less than one chance in 10,000 over the first 10,000 years after closure of leading to releases of radionuclides to the accessible environment.	The evidence indicates that this favorable condition is not present at Yucca Mountain: the higher bound on the probability of a basaltic event is estimated at slightly greater than one chance in 10,000 over the next 10,000 years; consequences of other tectonic processes or events are not expected to increase potential for release because low ground-water flux and long travel times are expected to prevent release at the accessible environment for at least 10,000 years following closure.

Table 2-9. Summary of Environmental Assessment Findings for Postclosure Tectonics (DOE, 1986) (continued)

Condition	DOE Finding
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.	1. The evidence indicates that this potentially adverse condition is present at Yucca Mountain; Quaternary volcanism 230,000 years and older and recurrent Quaternary faulting are found in the vicinity of the site.
2. Historical earthquakes within the geologic setting of such magnitude and intensity that, if they recurred, could affect waste containment or isolation.	2. The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: the historical record and geologic evidence indicate no large earthquakes that would be expected to affect containment or isolation if they recurred.
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.	3. The evidence indicates that this potentially adverse condition is present at Yucca Mountain: future increase in frequency or magnitude of earthquakes at or near Yucca Mountain cannot be ruled out on the basis of available information.
4. More-frequent occurrences of earthquakes of higher magnitude than are representative of the region in which the geologic setting is located.	4. The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: the earthquake frequency and magnitude for the geologic setting are the same as or less than the frequency and magnitude of the region.

Table 2-9. Summary of Environmental Assessment Findings for Postclosure Tectonics (DOE, 1986) (continued)

Condition	DOE Finding
POTENTIALLY ADVERSE CONDITIONS	
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.	5. The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: landslides, subsidence, and volcanic activity are not expected; even if they occurred, they would not be expected to cause surface-water impoundments or change the regional ground-water flow system.
6. Potential for tectonic deformations--such as uplift, subsidence, folding, or faulting--that could adversely affect the regional ground-water flow system.	6. The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: large-scale structures control the ground-water system, and tectonic deformations of a magnitude or scale to affect the regional flow system are not expected.

California); 1908, M=6, 110 km southwest of Yucca Mountain (Death Valley, California); and 1966, M=6, 210 km northeast of Yucca Mountain. No significant effect on waste containment or isolation would be likely if any of these events were to recur.

The DOE concluded that the third potentially adverse condition is present at Yucca Mountain. The principal considerations supporting the conclusion were (a) Yucca Mountain and a large area to the west and south have a low historical level of seismicity relative to other areas of the geologic setting, and the seismicity might therefore be expected to increase in the future; (b) 32 faults within an area of 1,100 km^2 offset or fracture Quaternary deposits; (c) the potential for renewed activity, based on in situ stress and microseismicity, is believed to be the greatest for north-striking faults, which are abundant in the southern Great Basin, including the vicinity of Yucca Mountain; and (d) focal depths for earthquakes in the southern Great Basin indicate the possibility of faults that are capable of producing large earthquakes.

The fourth potentially adverse condition was determined not to be present at Yucca Mountain. The evaluation for potentially adverse condition (2) is applicable to this condition. Both the frequency and magnitudes of earthquakes at and near Yucca Mountain are less than are characteristic of the geologic setting and the region and, therefore, there was no assurance that they will not increase.

The DOE took the position that the fifth potentially adverse condition is not present at Yucca Mountain, because of the lack of geomorphic evidence for large landslides or subsidence and the very small likelihood of volcanic eruptions. The evaluation further concluded that such tectonic processes, even considering expected climatic conditions over the next 10,000 years, are unlikely to impound sufficient surface runoff to change the regional flow system.

Finally, DOE concluded in the EA that the sixth potentially adverse condition is not present at Yucca Mountain. The evaluation reviewed approximate rates of relative vertical movement during the late Neogene and Quaternary at 12 locations in the southwestern Great Basin, concluding that the cumulative offsets over 10,000 years (<1 m at 7 sites, 1-4 m at 4 sites, and 18 m at 1 site) are small in comparison to the scale of structural features that control the present ground-water system.

2.3.7.3.2 Review of Postclosure Tectonics Information Obtained since the Environmental Assessment

The collection of field data since the EA was published has been limited principally to continued monitoring of seismic and hydrologic characteristics of the Yucca Mountain region and to limited collection of water and rock samples for chemical and isotopic analyses. However, there have been additional compilations, analyses, and interpretations of data, including information from other areas that are pertinent to understanding the effects of postclosure tectonism. These are summarized below with respect to the sets of required information ("models") described in Section 2.3.7.2.2.

2.3.7.3.2.1 Tectonic Models

The EA considered two basic tectonic models for the Yucca Mountain area. The first was a caldera model, in which the faults near the potential repository block were portrayed as subsidiary features resulting from inferred caldron subsidence in Crater Flat. The second was a Basin-and-Range model, in which crustal extension is accommodated by a combination of N-striking normal faults and NE- and NW-striking strike-slip faults that penetrate to the brittle-ductile transition. More recently, in the Site Characterization Plan for Yucca Mountain (DOE, 1988a), detachment faulting (low-angle extensional faulting) of various styles and planar-rotational faults (producing a "tilted-domino" block structure), whether deep-seated or terminating on an underlying detachment, have been recognized as possible alternatives to the interpretations in the EA.

Use of Terms

As used in this report without qualifying terms, a detachment fault (or simply detachment) is a low-angle extensional fault within the brittle crust, whether regional or local in areal extent. No implication as to the amount of displacement is intended. The degree of mechanical coupling between the rocks below and above a detachment may vary spatially and temporally, and styles of subsidiary faulting above the detachment are not specified. The subsidiary faults may include additional shallower detachments, planar normal faults that abut downward into an intensely sheared detachment, or listric normal faults, which decrease in dip downward to merge into the detachment surface. Local variations of stress and preexisting geology, particularly near the edges of the upper plate(s), may result in subsidiary strike-slip faults, reverse faults, dip-slip faults that increase in dip with depth, oblique-slip faults, or bending of the upper plate about a steeply plunging axis. Where the special case of essentially lateral dislocation between the brittle crust and underlying ductile deformation is intended, it is specified in the context. The boundaries of such a deep-seated detached plate ideally would be high-angle strike-slip faults and listric faults of such large radius of curvature that, near the land surface, they would be indistinguishable from normal faults that intersect the brittle-ductile transition at high angles. At this scale there may be a loss of distinction between detachment and deep-seated "Basin-and-Range" styles of faulting in terms of their seismic and hydrologic significance.

Depending on its age, the proposed detachment faulting in the vicinity of Yucca Mountain (see, for example, Scott, 1990) has differing implications for site characterization and performance evaluation. If the detachment structures are very old and overprinted by young tectonic features, they may have little significance for earthquake-hazard or hydrologic studies, but they may laterally displace still older structural and volcanic features. If the detachments are active, paths of upward magma migration might still be offset somewhat along the detachment surface, and the fracturing that may accompany upper-plate movement may dominate the hydrogeologic character of the area. Subsidiary faults in the upper plate, depending on plate thickness, might have limited potential for seismic energy release, whereas the greater seismogenic potential may actually be associated with deeper faults that may not be readily identified beneath the detachment. Because of the ranges of the possible significance of different tectonic styles or models, the principal evidence for these models and their significance to this evaluation of postclosure tectonics are discussed in greater detail below.

Regional and Local Evidence for Detachment Faults

The basis for the detachment-fault model in the southern Great Basin has been summarized recently by Scott (1989a, 1990), who cites evidence throughout the region for westward to southwestward migration of gentle doming and multiple levels of west-dipping detachment surfaces. He interprets three levels of low-angle normal faults mapped by Burchfiel (1965) in lowermost Paleozoic and upper Precambrian rocks in the Spring Mountains, 45 km southeast of the Yucca Mountain site, possibly to be part of a relatively deep regional detachment that may now surface at the edge of the Precambrian core complex in the Bullfrog Hills (Maldonado, 1985; 1990b) and in the northern part of Bare Mountain (Monsen et al., 1990), respectively about 40 km and

15 km west of Yucca Mountain. However, Scott (1989a, 1990) also discusses probable shallower, more local detachments identified by seismic investigations in Mid Valley (McArthur and Burkhard, 1986) (25 km east of Yucca Mountain), by mapping of exposures of the Tertiary-Paleozoic contact north of Mercury (Myers, 1987) (40 km east of Yucca Mountain), and by mapping of low-angle faults within the Tertiary and Paleozoic sections of the Calico Hills (Simonds and Scott, 1987) (about 19 km northeast of Yucca Mountain). Common features of the exposed faults are structural discordance with termination of dipping stratigraphic contacts and faults within the upper plate at its base, and structural and textural evidence of shear displacement parallel to the contact of the upper and lower plates.

In addition to the several references cited in the SCP (DOE, 1988a), the following papers discuss the evidence for one or more detachment plates at Yucca Mountain itself: Scott and Rosenbaum (1986); Scott and Whitney (1987); Hamilton (1988); Scott (1989a, 1990); Fox and Carr (1989); and Spengler and Fox (1989). In the composite detachment model of these authors, as recently summarized by Scott (1990), the high-angle north-striking faults that intersect the surface at and near Yucca Mountain decrease in dip listrically with depth, merging with an underlying low-angle extensional fault within the brittle crust. Scott (1989a, 1990) also discusses evidence that the rate of displacement along the detachments decreased markedly before deposition of the 11-million-years-old Timber Mountain Tuff, but that much less extension continued into the Quaternary along a shallower, secondary fault system. Movement on faults in the upper plate (or uppermost of two or more stacked plates) would be limited in depth of penetration, possibly placing constraints on the depth to which hydraulic pathways would be developed or refreshed. The depth limitation might be expected to limit also the seismic energy released by fault movement in the upper plate, but this may be a moot point if faulting above the detachment is coupled to deep faulting beneath. In fact, detachment of near-surface rocks may be a passive means of accommodating deep strike-slip fault displacement where the shallow section is imperfectly coupled to deeper rocks; this has been proposed by Scott and Rosenbaum (1986) to be the origin of the rotation of the tuffs about a vertical or nearly vertical axis at central and southern Yucca Mountain.

The east-bounding breakaway zone for the detachment with Quaternary movement beneath Yucca Mountain is proposed to occur about 2 km east of the potential repository site, along the Paintbrush Canyon fault. Fox and Carr (1989) suggest that this detachment occurs at the Tertiary-Paleozoic contact beneath Yucca Mountain, though they do not exclude the possibility that it is deeper. A generalized cross section in Scott (1989a, Figure 2) indicates a westward thickening of the upper plate beneath Yucca Mountain, in part because of topographic rise, from about 2.5 km to about 4 km. Young et al. (1991) applied computer techniques in a geometric-kinematic analysis of the geologic observations of Scott and Bonk (1984) and data from a drill hole that penetrates Paleozoic rocks at a depth of about 1.2 km (Carr et al., 1986). They suggest that the cross section cannot be balanced with the representation that the Paintbrush Canyon Fault merges listrically into a detachment at the base of the Tertiary section; rather, they propose that the detachment must occur at a greater depth, in the range of 3.5 to 6 km. The differences between these interpretations probably cannot be resolved, nor can other alternatives be identified, until the structural architecture is explored in greater detail by intensive geologic studies, including mapping, and to greater depths by geophysical techniques and possibly deep drilling.

Alternative Interpretations of the Evidence

Low-angle, even near-horizontal normal faults have been explained in the literature by mechanisms other than detachment faulting, as defined above to occur within the brittle crust. For example, Proffett (1977) proposed that the basic style of faulting in the Yerington district of western Nevada is deep-seated listric faulting, steeply dipping near the surface but decreasing in dip with depth until the extension is accommodated by ductile flow. Where segments of faults that were originally deep are now exposed, they dip at very shallow angles, even forming apparent low-angle reverse faults. Proffett (1977) suggests that original dips have further decreased by two mechanisms. First, there is evidence of substantial westward tilting in the Yerington region, such that the east-dipping faults that dominate in the area were rotated to shallower dips. Second, in the Yerington district, the positions of new faults tended to migrate westward or into the footwall blocks of previous faults. The tendency for extensional openings at the shallow, steeply dipping fault segments was accommodated principally by west-dipping sagging of the hanging wall, rather than by antithetic faults, further decreasing the dip of older faults close to their successors (Proffett, 1977).

Wright (1989) accepts the existence of detachment faults in the region within and east of Death Valley, but he argues that, beginning 16 to 14 mya, this region was divided into structural blocks by major strike-slip and normal faults. He proposes that the detachments, rather than being regional features, are unconnected local features within the individual blocks. The emphasis of Wright's (1989) synthesis of mapped faults and gravity data is the accommodation, beginning in the mid-Miocene, of right-stepping strike-slip fault zones by en echelon, obliquely oriented normal faults, "pull-apart" basins, and associated igneous activity. In his interpretation, the Amargosa Desert and Crater Flat, respectively south and west of Yucca Mountain, are within a zone of pull-apart basins termed the Amargosa Desert Rift Zone (ADRZ). He relates the ADRZ genetically to the Pahrump Valley and Stewart Valley right-lateral strike-slip faults which, if projected to the northwest, coincide approximately with the Walker Lane structural zone. Although Wright (1989) notes that Quaternary faults in Pahrump Valley and western Crater Flat follow those established in mid-Miocene time, he does not address the possible relation of these structures to Pliocene-Quaternary basaltic volcanism in the region. Schweikert (1989), however, suggests that the northwest alignment of basaltic cones in and northwest of Crater Flat may indicate the presence of a major right-lateral strike-slip fault that is not evident at the alluvial surface of Crater Flat.

Controls on Patterns and Characteristics of Volcanism

A series of papers by Crowe and his colleagues (Vaniman and Crowe, 1981; Vaniman et al., 1982; Crowe et al., 1983a; Crowe, 1986) discusses the petrology and geochemistry of the Pliocene-Quaternary basalts of the southern Great Basin, inferring that the magma chambers must be at or below the crust-mantle boundary. Crowe et al. (1983b) defined a volcanic zone (DVPRVZ) extending from Death Valley northward to the Pancake Range in Central Nevada, suggesting regional structural control of basalt centers. Carr (1984) suggested that some of the Pliocene-Pleistocene basalt centers occur along northeast-trending rifts within the DVPRVZ. North-northeast-trending structural controls also are components of later models proposed by Fox and Carr (1989), Smith et al. (1990), and Naumann et al. (1991).

In recent reassessments of volcanism patterns and characteristics in the Yucca Mountain area, Crowe and Perry (1989) and Crowe (1990) define the Crater Flat volcanic zone (CFVZ), favoring a northwest alignment of Pliocene-Pleistocene basaltic centers from Lathrop Wells cone (20 km south of the Yucca Mountain site) to the basalts of Sleeping Butte. This trend is compatible with that of the Walker Lane structural system, suggesting control of paths for ascending magma along northwest-trending, right-lateral strike-slip faults, as was suggested also by Schweikert (1989). Crowe and Perry (1989) consider a secondary northeast alignment of vents in clustered centers to reflect near-surface feeder dikes perpendicular to the direction of regional extension and least principal stress.

Smith et al. (1990) chose to define their area of most recent volcanism (AMRV) based only upon the factor of age, and they did not include magma composition and tectonic setting as criteria. The inclusion of the 2.8 Ma basaltic andesite of Buckboard Mesa allows Smith et al. (1990) to define an elliptical AMRV that encompasses Yucca Mountain. However, it should be noted that all Quaternary (<1.6 Ma) basaltic eruptive centers near Yucca Mountain occur inside the northwest trend of the CFVZ. In the CFVZ model, the geochemically similar basalts erupted since 3.7 mya ago within the northwest alignment of the CFVZ are distinct from the basaltic andesite of Buckboard Mesa. The Crowe and Perry (1989) analysis is considered to be more rigorous, but further investigations are planned to examine the structural controls on basaltic volcanism. The structural controls on volcanism are important components of an overall understanding of Quaternary tectonism. A direct linkage of faulting and volcanic activity was proposed by Fox and Carr (1989), who deduced from the common occurrence of volcanic ash within the north-striking fault zones near Yucca Mountain that the Quaternary faulting and nearby basaltic volcanism have been coeval.

Crowe (1991b) has suggested that basaltic volcanism in this extensional setting tends to occur within alluvial basins or along range-front faults, but that it is rare in the range interiors. However, there are examples of volcanic centers in uplifted range blocks, such as the Fortification Hill volcanic field south of Lake Mead and basalts in Reveille Range in south-central Nevada (Smith et al., 1990), as well as the intracaldron basalts of the Lunar Crater Field (Crowe et al., 1986). This suggests that gross topography may be related to the occurrence of basaltic centers only where it accurately reflects deep crustal structure, a relationship that is probable but not fully demonstrated near Yucca Mountain.

Evidence from Patterns of Fault Movement

The geochemically indicated ascent of the basalts along northwest-striking, deeply penetrating faults and the temporal coincidence of volcanism with movement on the north-striking faults near Yucca Mountain provide strong grounds for inferring a kinematic linkage between the two directions of faulting. If the north-striking faults represent only shallow, brittle failure within a detachment plate, the plate must be sufficiently coupled to rocks beneath the detachment to deform in direct response to deeper fault movement. Alternatively, the north-striking faults may be deep-seated structures that accommodate releasing bends resulting from offsets or changes of direction of the strike-slip fault segments (as stated by Cambray in Younker et al., 1992).

The deep-seated accommodation of right-stepping offsets is consistent with Wright's (1989) hypothesis for pull-apart basins, filled by thick volcanic rocks and sediments, beneath the Amargosa Desert and Crater Flat. Irregular boundaries, formed in part by secondary reentrants into the footwalls, probably are part of an evolutionary reestablishment of strike-slip motion through inherently unstable releasing bends (Ellis and Trexler, 1991).

The Las Vegas shear zone, a major right-lateral structure that strikes about N65°W on average, loses clear expression at its northwest end, about 50 km southeast of Yucca Mountain. If projected to the northwest, it would intersect the projected Walker Lane trend (N35°-40°W) in the vicinity of several faults that strike west-northwest in northern Yucca Mountain. The Las Vegas shear zone is aligned in the direction of the current extensional axis and is interpreted to have been inactive since about 11 ma (Fleck, 1970; Bohannon, 1983). Therefore, it seems unlikely to be temporally related to the Pliocene-Quaternary volcanism or fault displacement, but it may have contributed to the development of the prominent Miocene structural depression beneath Crater Flat.

O'Neill et al. (1991) describe NW-trending pull-apart structures at Yucca Mountain that are structurally linked to the N-striking faults, which display dominant normal dip slip and auxiliary left-lateral slip. Scott and Rosenbaum (1986) and Scott (1989a, 1990) considered the southward-increasing clockwise rotation of Yucca Mountain about a vertical axis, which is indicated by paleomagnetic data, probably to indicate interaction of an upper detachment plate with right-lateral oroclinal bending and shearing associated with the Walker Lane structural belt beneath the detachment surface. O'Neill et al. (1991) consider this clockwise rotation, the left-lateral oblique slip on the north-striking faults, and the northwest-trending pull-apart zones to be consistent with "domino style" rotation of rigid fault blocks. These features also are consistent with deformation within a pull-apart structure.

Although considerable progress has been made in understanding the near-surface structural features, extending this understanding to depths of several km in order to infer their seismogenic, volcanic, and hydrologic significance remains elusive. However, modern data on seismicity and ground-water temperatures indicate the importance of gaining an understanding of the deep structures.

Evidence from Seismicity and Heat Flow

Current seismicity in the immediate vicinity of Yucca Mountain is very low, but earthquakes have been recorded in the area at depths as great as 15 km (Rogers et al., 1987b). The deeper historical earthquakes are dominated by strike-slip focal mechanisms. Although the seismicity supports the presence of deeply penetrating faults, it does not preclude interpretations of shallower detachment faulting. The focal mechanisms for the deeper earthquakes may suggest mechanical decoupling from an upper plate in which a normal-faulting stress regime has been interpreted from borehole hydrofracture testing results (Stock et al., 1985) and paleoseismic studies. Historical earthquake locations in the southern Great Basin do not correlate well with major faults at the surface (Rogers et al., 1987b), whereas Coppersmith (1990) notes that inversions of teleseismic data for several Basin-and-Range earthquakes show them to be associated with moderately to steeply dipping faults rather than subhorizontal reflectors seen on seismic-reflection data. dePolo et al. (1990) suggest that partial decoupling within the upper crust may explain the complex surface-rupture patterns (distributed faulting) of several historical Basin-and-Range earthquakes. Partial decoupling is consistent also with the coincident west-northwest direction of the least principal stress for both shallow (hydrofracture) and deep (focal-plane) determinations (Rogers et al., 1987b) and with the oblique sense of movement on some of the faults in the vicinity of Yucca Mountain. If at lease partial decoupling of an upper plate from the underlying seismogenic zone is demonstrated, paleoseismic investigations in the immediate vicinity of the Yucca Mountain site may have limited application in forecasting ground-motion characteristics; however, local paleoseismic data would still be needed in predicting the probability of primary and secondary faulting within the repository.

Using the data of Sass et al. (1988), Szymanski (1989) constructed a generalized map showing subsurface temperatures at Yucca Mountain at a depth of 350 m. Fridrich et al. (1991) constructed a similar map but based it on temperatures at the water table. The maps give similar results, showing positive anomalies of several degrees Celsius along the Solitario Canyon fault and of a few degrees between Yucca Mountain and the Paintbrush Canyon Fault. Szymanski (1989) suggested that the anomalies overlie hydrothermal convection in the fault zones, whereas Fridrich et al. (1991) attribute the anomalies to upward leakage along the faults of water flowing generally southward in the deep (>2 km) Paleozoic rocks, which is within the normal regional flow system and without significant thermal influence on this system. Although the interpretations differ, they both require that the north-striking normal faults both east and west of Yucca Mountain penetrate and provide hydraulic pathways in the Paleozoic rocks.

Most descriptions of the more recent tectonic models have not addressed possible changes in the probability of fault displacement within the potential repository. However, Coppersmith and Youngs (1990) consider secondary faulting potentially to increase the frequency of waste-canister failure by as much as an order of magnitude, relative to the frequency estimated to result from only primary fault movement. Extensive field mapping, remote sensing, and geomorphic studies of the area have not revealed any faults of significance other than those that have been recognized since the mid-1980s (DOE, 1988a). All the faults for which evidence of Quaternary movement is currently available are outside the design repository boundaries, and they all achieved most of their displacement before 11 mya; the age of the Timber Mountain Tuff (Fox and Carr, 1989). The Ghost Dance fault, which strikes northward through the proposed repository area is covered by a thin veneer of young alluvium in only a few washes. Although Quaternary movement is unlikely, it has not yet been ruled out because of the very limited evidence. Lee et al. (1991) note that the current waste-emplacement strategy is to avoid known faults and faults or fracture zones identified during excavation of the repository. They also present results of probabilistic modeling of exceedance rates for fault ruptures of 5 and 50 cm on the Ghost Dance fault. Using the most conservative ("high seismicity") of their three models, they conclude that direct or indirect rupture effects that would compromise waste-canister performance are highly unlikely.

dePolo et al. (1990) define the "maximum background earthquake" (MBE) as the largest earthquake that can occur without primary surface rupture. They suggest "that the MBE for the Basin and Range Province is at least magnitude 6.3 and may be as high as magnitude 6.8," basing their conclusion on analysis of 38 historical earthquakes in the Basin and Range Province. The upper bound for the MBE, a local (M_L) or surface-wave (M_s) magnitude 6.8, is based on the 1925 Clarkston, Montana, earthquake. Doser (1989) has determined an instrumental moment magnitude (M_w) of 6.6 for that earthquake. Eight earthquakes of magnitude 6 to 6.6 produced secondary or distributed surface ruptures but no significant primary rupture. One of these, the 1934 Excelsior Mountain, Nevada, earthquake (M_L=6.3) was about 200 km northwest of Yucca Mountain in the Walker Lane, the zone of right-lateral shearing that has been postulated to continue southeastward through the vicinity of Yucca Mountain (Stewart, 1985). The Excelsior Mountain earthquake was preceded by the 1932 Cedar Mountain earthquake, also about 200 km northwest of Yucca Mountain and in the Walker Lane. The Cedar Mountain earthquake, M_s=7.2, produced a 60-kilometer discontinuous surface rupture with a maximum surface displacement of 2 meters and also a zone of secondary faulting 6 to 15 km wide. Molinari (1984) proposed that right-lateral strike-slip movement on an underlying fault was distributed upward through an upper detachment plate to produce the wide zone of deformation. Hardyman et al. (1975) and Hardyman (1978, 1984) proposed a similar model to explain many of the relationships associated with Tertiary detachments throughout the central Walker Lane. Although the Cedar Mountain earthquake was exceptional, the occurrence of distributed faulting at the smaller Excelsior Mountain earthquake indicates that this model should be considered in the evaluation of faulting potential at Yucca Mountain.

However, the topographic and surficial structural features in the vicinity of Yucca Mountain are not analogous to those of active segments of the Walker Lane, indicating a lack of continuity of this structural zone southeastward across the area into Pahrump Valley. Similarly, there is a lack of observational evidence for extending the Las Vegas shear zone west-northwestward to an intersection with the Walker Lane trend near Yucca Mountain. This may not be merely fortuitous and temporary. Rather, it could indicate a fundamental accommodation of deep-seated offsets of the potentially active strike-slip fault zones, which upon further kinematic analysis may be found consistent with the conceptual models of Wright (1989) or Cambray (In Younker et al., 1992). The accommodation faults, i.e., the left-lateral oblique-slip north-striking faults at and near Yucca Mountain (O'Neill et al., 1991; Whitney and Muhs, 1991) and the left-lateral northeast-striking faults of the Spotted Range-Mine Mountain zone (Carr, 1984) to the southeast and east of Yucca Mountain, may also be deep-seated structures. In this model, regional displacements might be accommodated locally by coeval smaller displacements on several faults within a moderately large area, consistent with the occurrence of indistinguishable tephra in fault zones both east and west of Yucca Mountain (Fox and Carr, 1989). Implications of this model are (1) the currently mapped faults are probably deep-seated and are the most likely local seismogenic sources, indicating that continued paleoseismic studies are pertinent, and (2) local energy release may be dispersed spatially and perhaps chronologically throughout the set of accommodation structures.

Evidence from Rates of Displacement

Although the paleoseismic data base is far from complete, interpretations of the existing information (Scott, 1990; Gibson et al., 1990) indicate that strain rates have decreased substantially from the Miocene maximum (13 to 11.5 Ma) to the Quaternary. On the basis of the work of Whitney et al., (1986) and Scott and Whitney (1987), Scott (1990) reports estimated slip rates for the period 11.5 mya to present to be 0.026 mm per year on the Windy Wash fault, 0.010 mm per year on Solitario Canyon and Paintbrush Canyon faults, and 0.029 mm per year on the Stagecoach Road fault. Two of these rates are at least an order of magnitude less than the geologic record indicates for the 13 to 11.5 million year period, and that for the Windy Wash fault is reduced by a factor of 3. The late Quaternary slip rate on the Windy Wash fault, 0.0015 mm per year during the last 270,000, is about half the slip rate during the last 3.4 million years (0.003 mm per year) (J. W. Whitney, oral communication, August 20, 1991) and is more than an order of magnitude less than the slip rate averaged over the last 11.5 million years. In Scott (1990), only maximum ages could be established for Quaternary units that are displaced by the Paintbrush Canyon and Stagecoach Road faults, resulting in calculated minimum slip rates, and dip-slip displacement was assumed. Respectively, these are 740,000 years ago and 0.006 mm per year for the Paintbrush Canyon fault (at Busted Butte) and 1.7 mya and 0.003 mm per year for the Stagecoach Road fault. More recently, Whitney and Muhs (1991) provide evidence that the Paintbrush Canyon fault at Busted Butte has oblique-slip displacement with a rake of about 45 degrees. The deepest soil exposed in a deep arroyo (about 20 m) has a dip-slip displacement of 4.1 m, or about 5.8 m of oblique-slip displacement. The soil is estimated to be 700,000 years old because it overlies an aeolian unit containing the 738,000 years old Bishop Ash and underlies a substantial thickness of deposits containing younger soils. The calculated oblique slip rate of 0.008 mm per year is probably close to the actual average rate over the 700,000 year period. The composite results indicate that, relative to the 11.5 million year slip rate, Quaternary slip rates were substantially less on the Windy Wash and Stagecoach Road faults, and somewhat less on the Paintbrush Canyon fault at Busted Butte.

Note, however, that rates of tectonic activity are typically variable, particularly within a small locality. Therefore, average slip rates over long time periods may differ greatly from those during episodes of greater or less activity, requiring that paleoseismic investigations be applied within a broad context of the tectonic history of the specific locale and its geologic setting.

Evidence from Other Tectonic-related Processes

As was stated in Section 2.3.7.2.2.(1), issue resolution requires that considerations of tectonic models address the potential for uplift, subsidence, folding, and the natural changes of the hydrothermal regime. Other than the possible minor continuation of detachment rotation, no significant folding, tilting, or vertical movement has been proposed for the Quaternary tectonic environment of Yucca Mountain. However, Fox and Carr (1989) cite geomorphic evidence for late Quaternary uplift of the Skeleton Hills-Mount Sterling area south of the Rock Valley fault, which is about 25 km southeast of Yucca Mountain.

The possibility of more regional gentle tilting, inferred from a southward decrease in elevation of apparent lake-shore deposits, was discussed by Carr (1984) and in the EA (DOE, 1986). Hay et al. (1986), Huber (1988), and Hoover (1989) conclude that the deposits in question mark isolated marsh and pond locations, for which southward decrease of elevation reflects down-gradient lowering of the discharges from the Pliocene-Pleistocene regional ground-water system. Additionally, Huber's (1988) geomorphic analysis of the Yucca Mountain area suggests relative tectonic stability since about 11 million years ago.

Fox and Carr (1989) and Spengler and Fox (1989) relate their interpretations of tectonic processes to hydrologic effects. The former paper proposes that episodic faulting has provided open pathways for the circulation of meteoric water or ground water, as indicated by precipitates of calcium carbonate and silica in the fault zones. The latter paper cites a southward increase of fault displacement and width of broken zones in proposing a corresponding southward increase of transmissivity; it further proposes that the cyclic faulting periodically refreshes the transmissivity of fault zones that might otherwise heal with chemical precipitates.

Szymanski (1989) has proposed the tectonic dominance of deep-seated faulting, driven by viscous flow in the upper mantle, on the geothermal regime and hydrology of the Yucca Mountain region. He relates the tectonic setting of the area to an incipient intracontinental rift zone, which is consistent neither with the geothermal regime (Sass et al., 1988; Dudley et al., 1989) nor with the regional structure. Szymanski (1989) attempts to establish cyclicity of the local tectonism, which is important to transient hydrologic control, from the chronology of secondary calcium carbonate in the region, which he concludes has been deposited by tectonically and hydrothermally driven ascending ground water. A large number of papers, which present incremental results of current investigations, have addressed the origin of the calcite-silica veins in faults near Yucca Mountain with the consistent conclusion that they formed beneath the soil zone as precipitates from infiltrating meteoric water. Among these are Taylor and Huckins (1986), Vaniman et al. (1988), Whelan and Stuckless (1990), Marshall et al. (1990), Quade and Cerling (1990), Cerling and Quade (1991), Kroitoru et al. (1991), Marshall et al. (1991), and Stuckless (1991). Although there is considerable evidence that Szymanski's basis for demonstrating tectonic cyclicity is incorrect, Whitney et al. (1986) and Fox and Carr (1989) propose that extensional episodes (not necessarily cyclic) may have an average period of not greater than 75,000 years, based on the composite slip of the Windy Wash fault during the last 300,000 years.

<u>Summary of tectonic models</u>. The foregoing discussion does not support uniquely any single tectonic model for the Yucca Mountain area. The evidence

is at least permissive of the alternatives listed below, and combinations of some features are likely.

1. Regional detachment model. In this model, regional extension is accommodated above the brittle-ductile transition by detachments along shallower surfaces within the brittle crust. Strike-slip, normal, and even reverse faults may develop to accommodate differential rates or directions of movement within a detachment sheet, but these faults are unlikely to cut across detachment surfaces. Structures visible at the surface are limited to the uppermost sheet and provide little if any information about deeper structure. Persistence of cross-cutting pathways for basaltic volcanism would indicate that extension by quasi-horizontal detachments has ended, being replaced by a different mode of extension.

2. Shallow-detachment model. This model entails at least partial decoupling of the near-surface crust (not more than several km in thickness) from deeper parts of the brittle crust, which is extending by failure along high-angle faults (predominantly strike-slip) that penetrate to ductile crust. The upper sheet (which may be subdivided into more than one sheet) fails complexly in response to both lateral and vertical movements of deeper blocks, and surface structures may bear little apparent relationship to seismogenic structures or deeply penetrating faults that serve as magma pathways. Underlying fault displacement may cause a variety of surface expressions, such as distributed fault zones, sag or collapse structures, vertical-axis bending, or lateral sliding of detachment-sheet segments. In terms of seismogenic capability, this model provides the possibility of undetected and historically inactive faults beneath the detachment surface (possibly as shallow as 2 to 3 km beneath the proposed repository), limiting our capability to place constraints on potential earthquake magnitudes, ground motion, and distributed faulting at the repository site.

3. Caldera model. Although different in origin, the caldera model presented in the EA (DOE, 1986) is similar in some aspects to the shallow detachment model. The near-surface structures at Yucca Mountain are local and relatively shallow (< 5 km), associated with detachment(s) of (or within) the Tertiary volcanic rocks and slumping or lateral sliding toward the presumed volcanic depression beneath Crater Flat. Structural control of volcanism may be related to the caldera structure or to a later change of tectonic style, such as reestablishment of Walker Lane deformation.

4. Segmented strike-slip model. Strike-slip faults comprising laterally offset or intersecting segments are the basic mode of extension but are replaced locally by accommodating pull-apart or sag basins, which are bounded by normal or oblique-slip faults. At least the principal accommodation faults penetrate to ductile crust. The upper crust may be detached locally in response to vertical dislocations. Displacement on the strike-slip fault is dispersed locally throughout the accommodation structure. Deterministic analyses of paleoseismic data from a single fault may underestimate

the energy release and, thus, ground motion in the vicinity of the accommodation structure. As noted above, segment offsets are inherently unstable and over geologic time through-going strike-slip faulting may be reestablished.

5. Normal-fault model. This model comprises subsets sharing the basic dominance of normal faults that penetrate the brittle crust to a depth (about 15 km) at which extension is accommodated by ductile deformation. Regionally the styles of faulting can include steeply dipping planar faults (horst and graben structure), tilted planar faults and interfault blocks (tilted domino structure), or listric (curving to progressively shallower dip with depth) faults on which the hanging-wall block rotates. On a regional scale, individual domains of normal-fault style may be separated by zones of strike-slip faulting, with associated edge effects such as vertical-axis drag rotation. If this model is appropriate for Yucca Mountain, the tilted fault blocks require either the listric or tilted-domino style. Furthermore, the influence of edge effects would be indicated by the southward increase of displacement and width of north-striking fault zones and by the vertical-axis rotation of the volcanic rocks. Locally, this model may be indistinguishable from the segmented strike-slip model, and the seismogenic implications of the two models are similar.

At this time there is no unambiguous evidence for distinguishing between the shallow-detachment, segmented strike-slip, and normal-fault models. The caldera model represents structures that are inherited from processes that ended locally by mid-Miocene time and, therefore, is an unlikely and non-conservative alternative for understanding Quaternary and future tectonism. Similarly, the regional detachment model does not readily explain the basaltic volcanism in Crater Flat unless the detachment complex reflects an extinct, superseded process. A complicating factor is that shallow or thin-skinned detachments could develop locally within the area as secondary features were superimposed on deep-seated strike-slip and normal-fault styles as proposed by Wright (1989). In view of the rather compelling evidence for both deep-seated faulting and detachment structures in the vicinity of Yucca Mountain, the coexistence of these styles currently seems to be likely. Nonetheless, in evaluating the site with respect to the qualifying condition of this guideline, it is prudent to consider the above models, or combinations, to be plausible, but not to the exclusion of considering other alternatives.

In terms of faulting and ground-motion characteristics that are expected based on the currently known Quaternary record, i.e., the basis for evaluating the disqualifying condition, the persistence of tectonic activity on the principal north-striking faults is a significant characteristic. Most of the displacement on these faults occurred before about 11 mya, the age of the Timber Mountain tuff. Despite intensive study, Quaternary fault displacements have not been found at locations that do not exhibit Tertiary displacement. The persistence of activity on long-established structures suggests the involvement of a substantial thickness of the brittle crust. In turn, this suggests that the segmented strike-slip model, the normal-fault model (with edge effects), or the shallow-detachment model with an upper-plate thickness of at least several kilometers represent the causative processes. Hidden underlying faults, if present, are therefore likely to be quite deep, and the north-striking faults probably penetrate deeply. Predictions made with the assumption that the presently known north-striking faults are the controlling seismogenic structures are unlikely to result in significant underestimates of ground-motion intensity.

2.3.7.3.2.2 Ground-motion Models

The principal change relating to predicting ground motion since release of the EA has been the recognition that the Paintbrush Canyon fault is probably the controlling fault for estimates of ground motion at the repository. Lee et al. (1991) indicate that the probability of exceeding a peak horizontal ground acceleration (surface) of 0.6g at the repository in a 1,000-year period is 10 percent, half of that owing to the Paintbrush Canyon fault and the other half to all other sources composing the background. By analogy with the estimates of Gibson et al. (1990) for slip rates on the Paintbrush Canyon and Bow Ridge faults, Coppersmith and Youngs (1990) provide preliminary estimates of annual frequency and magnitude for earthquakes on seven faults at and near the Yucca Mountain site. For an annual frequency of 10^{-5}, they estimate moment magnitudes (M_w) of >6.4 for the Paintbrush Canyon fault and >6 for the Solitario Canyon and Windy Wash faults. They have not yet estimated ground-motion characteristics resulting from these earthquakes, emphasizing the preliminary nature of their estimates, the need for additional paleoseismic work, and their judgment that fault rupture rather than ground motion is the more important concern for the postclosure period.

Yucca Mountain is characterized by very steep slopes, mantled in places by colluvial boulders that are coated by well-developed desert varnish. These features and methods for estimating their antiquity are discussed in Section 2.3.5.3.2.1 relative to their use in demonstrating low rates of erosion (Whitney and Harrington, 1988 and in preparation). Although slope failures and rockfalls occur commonly near epicentral zones of major earthquakes, the inverse problem--that of estimating peak ground motion experienced by still-stable slopes--has apparently not been addressed. That varnished colluvial boulders, including many in precarious positions, have remained unrotated for apparently hundreds of thousands of years qualitatively suggests that severe ground acceleration approaching 1g has not occurred at Yucca Mountain during this period. This observation, however, has not been calibrated by systematic correlation of rockfalls or boulder rotation with measured ground motion.

Rogers et al. (1987a) and URS/Blume (1986) have compiled abundant probabilistic data and analyses on the seismicity of the southern Great Basin and expected ground motion at Yucca Mountain. Phillips et al. (1991) used measurements from underground nuclear explosions (UNEs) at the Nevada Test Site to examine source-direction and station effects on ground motion. They provide comparative measurements at the surface and at the approximate design depth of the repository. In terms of pseudo-relative velocity (PSRV) spectra, which are useful for design, ground motions at depth were typically a factor of two or more smaller than that at the surface, although for some stations, there was no significant difference (Phillips et al., 1991).

Strong-motion effects on tunnels were recently reported by Phillips and Luke (1991), who also use a UNE as a surrogate for nearby fault movement. In a thoroughly instrumented experiment, they observed the effects of a magnitude 5.0 explosion at a distance of about 0.5 km. The maximum horizontal ground acceleration was 27.6g, and maximum velocities and displacements were 2.3 m/s and 13 cm. Damage to the tunnel was "minor," although there was discernible fracturing and tunnel deformation. Phillips and Luke (1991) point out that damage to underground openings from earthquakes is rare, provided that the opening is not affected directly by fault displacement. They also note that damage decreases as the ratio of seismic wave length to dimensions of the opening increases; this suggests that damage to waste-emplacement holes in the floor of a repository is unlikely to be significant from natural ground motion.

Lee et al. (1991) emphasize repeated occurrences of ground-motion events as being potentially more damaging in the aggregate than individually. They suggest design considerations to take this into account.

2.3.7.3.2.3 Engineered Barrier System Damage and Degradation

Discussion in the SCP (DOE, 1988a) of EBS damage and the resulting release of radionuclides essentially replicated that in the EA, concluding that the small flux of water through the unsaturated zone and retardation processes precluded release of radionuclides to the accessible environment for long beyond 10,000 years. The reports cited previously by Coppersmith and Youngs (1990), Lee et al. (1991), and Phillips and Luke (1991) discuss possible EBS damage. However, these reports emphasize the initiating events, primary and secondary fault rupture and recurrent ground motion. Other than that of Phillips and Luke (1991), no analyses have been identified during this evaluation that address EBS damage, degradation, and release of radionuclides given the occurrence of an initiating event.

2.3.7.3.2.4 Strain-response Models

Szymanski (1989) proposed that stress relief and redistribution accompanying faulting in the extensional tectonic environment of Yucca Mountain could produce the following effects: (a) sudden rise of the water table in an extensive area near the active fault, resulting from increase of compressive stress; (b) upward seismic pumping of ground water along the fault zone; (c) sustained hydrothermally driven circulation in the fault zone that may rise significantly above the previous water table; and (d) reduction of transmissivity in areas between dilated faults, requiring larger gradients and water-table altitudes to drive the existing flux of ground water. Szymanski cites several geologic and hydrologic characteristics of the region as evidence that these mechanisms are, or have been, active in the Yucca Mountain area, among which are (a) calcite and silica infillings in fault zones and fractures, which he interprets to record discharge to the surface; (b) variable and, in places, large gradients of the potentiometric or water-table surface; (c) vertically and laterally variable conductive heat flow and subsurface temperatures; and (d) variable ground-water chemistry, particularly in unsaturated-zone water.

Szymanski's hypothesis and field evidence have been subjected to extensive past and ongoing review. A project-staff technical review (Dudley et al., 1989) of the November 1987 draft noted (a) that many of the physical processes invoked are plausible, though probably not at the scales and durations of effects proposed by Szymanski; (b) that the model was not presented with sufficient rigor and quantification to be tested; and (c) that simpler hydrogeologic explanations for the proposed field evidence would more likely prevail as further information is obtained. A five-member external panel has been commissioned to evaluate the Szymanski (1989) report but has not yet submitted its findings. In addition, a larger panel formed by the National Academy of Sciences to provide an evaluation of coupling of hydrologic, tectonic, and hydrothermal processes (HYTEC panel) plans to comment on the Szymanski hypothesis as part of its broader role. The comments of these panels are likely to influence the DOE's future position regarding the transient hydrologic effects of postclosure tectonism.

In the May 1991 meeting of the American Geophysical Union in Baltimore, MD, a full-day session was devoted to the potential of tectonism and volcanism for creating water-table excursions, with discussions including conceptual models, analytical models, and field observations. Carrigan and King (1991) reported on computer simulations to evaluate potentiometric and water-table rises from seismic pumping and fracture closure. Results indicate the plausibility of confined pore-pressure increases exceeding 200 bars in the hanging wall of a magnitude 6.8 normal-fault event, but resulting in water-table rises of only centimeters to a few meters. For realistic ranges of rock hydraulic properties, the increases are transient, lasting weeks to months. Rudnicki (1991) predicts similarly high confined pore pressures, possibly causing the wallrock to implode into a fault zone. His results, however, show that pore pressure decays rapidly as water flows toward a fault and, therefore, that it is unlikely that large gradients can be maintained long enough to cause a significant volume of fluid flow. These predictions are consistent both with other similar calculations and with historically observed hydrologic effects of earthquakes in extensional environments, such as the well-studied 1983 Borah Peak, Idaho, earthquake ($M=7$) (Waag, 1991; Wood, 1991; Muir Wood and King, 1991a,b). Sudden potentiometric (artesian) rises of at least 35 m occurred in the hanging-wall block about 4 km from the epicenter, and produced sediment boils, piping, and a short-lived lake, which indicates that the water-table rise was much less than the potentiometric rise. Increased streamflow was discernible for as long as six months over an area of 18,000 km^2; one warm spring increased in discharge by a factor of about 15 fifty days after the earthquake and in 1990 was still flowing at three times its pre-earthquake flow (Wood, 1991). Muir Wood and King (1991a) estimated the total release of water due to the Borah Peak earthquake to be about 0.4 km^3, the near-field strain to exceed 10^{-3}, and strains as great as 10^{-5} out to a distance of 60 km. Muir Wood and King (1991a) and Rojstaczer (1991) note that water-table declines often occur, as well, and attribute these to increased permeability and porosity from fracturing.

Using the geomechanically based model of Kemeny and Cook (1990) for estimates of water-table rise, Coppersmith and Youngs (1990) combine their tectonic model to predict the probability of water-table rise within 10,000 years. For a probability of 0.1, they predict a rise of 20 m for a large rock-mass compressibility of 0.4×10^{-10} Pa^{-1}. The probability of a 100-m rise, given this large compressibility, is about 0.001. For their preferred compressibility, 1.2×10^{-10} Pa^{-1}, the 0.1 probability is associated with a 5-m rise, whereas the 0.001 probability is associated with about a 40-m rise.

Although a consistent and quantitative understanding of strain effects has yet to be gained, the experience compiled and the modeling results indicate that water-table rises from tectonic strain are unlikely to exceed a few meters and that potentiometric surges on faults are unlikely to exceed tens of meters or to persist for more than a few months. It is cautioned, however, that currently available simulations may not test the range of geologic conditions and hydraulic parameters that realistically exist; nor have they examined the effects under higher degrees of saturation that may be associated with future climates.

2.3.7.3.2.5 Flow Models

The Postclosure Geohydrology Guideline Evaluation, Section 2.3.1, discusses post-EA information and analyses regarding the effects of faults, preferential pathways, and perched saturation zones within the unsaturated zone. Many conceptual refinements have been published (e.g., Hoxie, 1989), but there has not been significant change to descriptions in the EA in the aspects of the unsaturated zone that are pertinent to tectonic influences.

With respect to saturated-zone activities, there has been continued monitoring of water levels (Robison et al., 1988; Gemmell, 1990) and analyses of water-level fluctuations (Galloway and Rojstaczer, 1988; Luckey, 1990), but no significant tectonic effects have been identified. However, Winograd and Szabo (1988) have proposed a persistent decline of the water table in the southern Great Basin during the Quaternary because of increasing aridity caused by tectonic rise of the Sierra Nevada and other ranges.

Understanding of hydrogeologic controls on saturated-zone flow has advanced in several areas. Definition of the regional and local systems has benefited from data acquired by commercial exploration and maturing of conceptualization (Czarnecki, 1989a; Czarnecki and Luckey, 1989).

Two decades ago, Sass et al. (1971) proposed that subnormal heat flow in a large area of southeastern Nevada (the "Eureka Low") was caused by ground-water recharge and flow. Sass et al. (1988) have demonstrated that conductive heat flow in the vicinity of Yucca Mountain is also less than the regional average. Szymanski (1989) proposed that heat-flow variations in the vicinity of Yucca Mountain are related to a transient state of stress, in turn controlled by deep crustal and subcrustal processes. Other workers, however, consider that the geothermal field in the relatively shallow crust (<2 km) is passively distorted by gravitational flow of ground water recharged from meteoric sources. Sass et al. (1988), Dudley et al. (1989), Dudley (1990a), and Fridrich et al. (1991) principally attribute the low heat flow at Yucca Mountain to lateral convective heat transport by ground water in the underlying Paleozoic rocks, although Sass et al. (1988) also consider the interception of heat by downward flow and removal of heat from the unsaturated zone by vaporization and advective moisture discharge. Similarly, Dudley (1990a) and Fridrich et al. (1991) propose that local variations of both heat flow and ground-water temperature reflect the varying depths and directions of flow imposed by geologic controls on the hydrologic system within and above the Paleozoic rocks.

The EA presented a preliminary potentiometric-level map for the site area defined by Robison (1984). The principal feature of this map is a large gradient of the potentiometric surface (an approximation of the water table) from the north and northwest toward the Yucca Mountain site. Several investigators have considered the causes and significance of this gradient, recognizing that water-table altitudes only 2 km north of the site exceed the design altitude of the repository. Most of the proposed causes (Czarnecki, 1989b; Sinton, 1989; Dudley, 1990a) involve hydraulic barriers, such as faults or igneous intrusions. Others suggest a substantial northward decrease of transmissivity, such as by alteration of the tuffs during Timber Mountain volcanism (11 mya) or due to the presence of the relatively impermeable Eleana Formation, a regional aquitard. In contrast, Szymanski (1989) interprets the hydraulic gradient, like thermal variations, to indicate transient thermal or stress conditions. Czarnecki (1989b, 1991b) modeled the effects of sudden removal of a narrow hydraulic barrier, concluding that the water table beneath the repository would not rise more than 10 to 20 m, substantially less than his predicted 130-m rise in response to a substantial climate change.

Fridrich et al. (1991) proposed that the large gradient results from downward diversion of flow along a northeast-trending fault zone, indicated by gravity and stratigraphic data, from the Tertiary volcanic rocks into the underlying Paleozoic rocks, diverting much of the southward flux within the tuffs beneath the site. Their conceptual model also calls for upward return flow into the volcanic rocks along faults east, west, and south of the potential repository site, based on elevated temperatures at the water table at and near the fault zones; this is consistent with the higher transmissivities, particularly to the south, along extensional faults as proposed by Fox and Carr (1989) and Spengler and Fox (1989). Although this conceptual model has not yet been extended to the required three-dimensional numerical model to test its significance with respect to future tectonism, an optimistic judgment might be reached that the current depth and apparent stability of the water table beneath the Yucca Mountain site owe in part to tectonic extension that is likely to continue with similar style in the future.

2.3.7.3.2.6 Probabilistic Volcanic-release Models

Crowe (1986) defines two basic approaches for assessing the hazards of basaltic volcanism at Yucca Mountain. The first is to reach subjective judgments based on the structure and geologic history defined by traditional geologic, geophysical, and geochronological studies. The second is to systematically estimate conditionally linked probabilities that (a) volcanism will occur within 10,000 years within the general vicinity of Yucca Mountain; (b) the volcanism will disrupt the repository; and (c) the volcanic disruption will result in releases to the land surface. Although the EA (DOE, 1986) discussed the regional tectonic setting and its possible relation to basaltic volcanism, the second approach to risk assessment was used, assuming random areal distribution of volcanic centers as was assumed in earlier analyses by Crowe and Carr (1980) and Crowe et al. (1982). The conditional probability that volcanism would occur at some time within the isolation period (10,000 years) and that it would disrupt the repository was estimated to be about 10^{-4}.

Combining the above approaches to consider the influence of structure and tectonic processes on the probability of disrupting the repository was advocated by Crowe (1986) and has been applied in later analyses (Crowe et al., 1989; Crowe, 1990; Crowe and Perry, 1989; Perry and Crowe, 1990). Although recent studies favor the definition of the Crater Flat volcanic zone (CFVZ) as a discrete, genetically related volcanic field, other structural controls discussed above in the context of tectonic models (Section 2.3.7.3.2.1) have been considered. Disruption probabilities for structural conditions that are credible in the context of geologic knowledge, given that volcanism will occur in the region, range from about 1.4×10^{-3} to 3.9×10^{-3}, with a mean value of $2.7 \times 10^{-3} \pm 0.8 \times 10^{-3}$ for the 10,000 year postclosure period of concern.

Both the ages of volcanism and the active lifetime of individual centers have received intense study, particularly with respect to the Lathrop Wells volcanic center, which was considered in the EA (DOE, 1986) to be about 230,000 years old. Crowe (1990) and Wells et al. (1990) present evidence from geologic, soils, and geomorphic studies that the Lathrop Wells center resulted from polycyclic eruptions with the latest occurring in late Pleistocene or Holocene time; they consider two earlier eruptive events, one at 60,000 to 105,000 years ago and another at 25,000 to 45,000 years ago. Champion (1991) and Turrin and Champion (1991) consider, principally from paleomagnetic and radiometric age data, that the cone is monogenetic and formed in a period of about 100 years about 130,000 years ago, an age determined by a statistically weighted average of K-Ar and Ar-40/Ar-39 dates that individually range widely. Crowe and Perry (1989) take these and other uncertainties into account in determining that the probability for the formation of a new volcanic center in the Yucca Mountain region is $2.3 \times 10^{-6} \pm 1.0 \times 10^{-6}$ per year. Combined with the subsequent conditional probability of repository disruption, the mean probability of new volcanism that would penetrate the site at least once in 10,000 years is about 6×10^{-5}, with a range of 2.5×10^{-5} to 1.2×10^{-4}. The mean probability has decreased by about a factor of 2 from that reported in the EA (DOE, 1986), and the calculated range has been reduced from a factor exceeding 150 to a factor of about 5. Numerous assumptions that are believed to be conservative underlie the probability estimates; evaluating the validity of these assumptions and their importance to the analysis is the focus of the future activities that are described in Section 2.3.7.3.3.

Crowe and his colleagues (Crowe, 1986; Crowe et al., 1986, 1988b, 1989; Wells et al., 1990) are currently reevaluating the third of the conditional probabilities, the likelihood of radionuclide releases that exceed regulatory limits, given that a new volcanic center disrupts the repository. Among the considerations are the dimensions of feeder dikes, ascension rates for the magma, the geochemistry of the magma (affecting depth of magma fragmentation), mechanisms of waste entrainment, the possibility of multiple eruptions at a new center, and the possibility of hydrovolcanic explosions.

2.3.7.3.3 Conclusions and Recommendations for Future Postclosure Tectonics Activities

Qualifying Condition

In Section 2.3.7.2.1 of this evaluation, four technical issues were proposed to encompass the concerns expressed by the qualifying condition and the guidance in 10 CFR Part 960. Resolution of these four issues would provide a strong indication that the site would qualify under the conditions specified.

The first technical issue addresses the effects of faulting or ground motion, including the subsequent action of water, on the integrity of the EBS. Although damaging fault movement or ground motion are not expected, as discussed in Section 2.3.7.3.3.1, neither have they been demonstrated to be so unlikely as to be considered inconsequential. Therefore, the guideline presently requires that their probabilities be established and the conditional consequences be assessed. Discussions in Sections 2.3.7.3.2.1 through 2.3.7.3.2.3 support a modest increase in confidence that EBS performance will be within the regulatory requirements: Ground motion is highly unlikely to cause damage to waste canisters, assuming reasonable conservatism in the design of canister emplacement. New faulting through the repository is very unlikely in view of current concepts of the tectonic setting, but the Ghost Dance Fault requires further study. Current understanding is inadequate to estimate, in a sufficiently meaningful way, the probabilities of fault movement or various levels of ground motion (including secondary faulting and recurrent ground motion), the initial effects on EBS integrity, or potential subsequent increases in rates of waste-package corrosion because of changes to the hydrologic system.

It is not clear that tectonics is the controlling process of concern with respect to gaseous releases to the accessible environment. Without considering tectonic processes, C-14 releases are predicted to have a significant probability of exceeding the regulatory limit, as is discussed more fully in Section 2.4. The incremental probability of additional releases from a tectonically induced loss of waste containment is very small in comparison, suggesting that the second technical issue might reasonably be considered resolved.

The possibility of aqueous releases, which are considered in the third technical issue, remains the area of greatest uncertainty in the qualifying condition for postclosure tectonics, principally because of the large number of specific concerns (Section 2.3.7.2.1). Definition of these concerns has progressed since preparation of the EA, and recent data and analyses indicates that eventual resolution of the concerns is probable. Presently, however, concerns relating to fault pathways and water-table rise, particularly in concert, have not been addressed in detail, nor are the processes understood sufficiently to estimate the consequences. On the basis of presently available information, tectonic processes, acting alone in the present hydrogeologic framework, are considered highly unlikely to cause a loss of waste isolation. If the current confidence in the waste-isolation capability of the unsaturated zone were to erode significantly, however, the necessary role of the saturated zone, which is more susceptible to tectonic damage than is the unsaturated zone, would increase in importance.

With respect to the fourth technical issue, release by volcanism, recent analyses indicate a modest decrease in the probability of a new volcanic center that would disrupt the repository, relative to the probability given in the EA. Further decreases may be possible if future calculations incorporate field and geochemical evidence of waning volcanism (Crowe and Perry, 1989). Additionally, correlation of Quaternary faulting, tectonic models and basalt eruption sites may suggest a greater degree of predictability than has been assumed in past evaluations. This work, however, will have to be reconciled with other less viable but permissive, structural models (Smith et al., 1990; Nauman et al., 1991). The least mature part of the risk assessment approach for volcanism is in understanding and treating probabilistically the effects of magmatic disruption of a repository. These disruptive effects are limited by the small subsurface area of basalt feeder dikes and the shallow depth of fragmentation of basalt magma.

In summary, the consensus of the Core Team is that current evidence continues to support the lower-level suitability finding made on the EA (Level 3). Although confidence is substantial, it is not yet sufficient to support the higher-level suitability finding for this qualifying condition (Level 4).

Disqualifying Condition

The consensus of the Core Team is that the evidence supports a conclusion that (1) the site is not disqualified and (2) information to be collected in the future is unlikely to result in disqualification under this condition (Level 2). This conclusion results from the lack of expectation that fault movement or ground motion will cause a loss of containment within the EBS, i.e., a negative answer to the first of the two questions posed in Section 2.3.7.1.1.

Yucca Mountain and the surrounding vicinity have been intensely studied by means of geologic mapping, geophysical surveys, remote sensing, and geomorphic analysis. Evaluations of the resulting geologic record, though preliminary, provide a reasonable expectation that Quaternary fault movement has occurred only on the principal north-striking faults, which formed in Miocene time and which have had continued or renewed activity in the Quaternary, but with small slip rates. The current state of stress in the shallow crust at Yucca Mountain is consistent with continued movement on these faults rather than initiation of new faults. Although distributive or secondary faulting is probably responsible for the closely spaced small-displacement faults west of the principal faults, such subsidiary faults have not been identified within the boundaries of the potential repository. Furthermore, there is no evidence to suggest that the small Tertiary faults, such as the Ghost Dance Fault, within the repository boundaries have Quaternary displacement. The combined evidence argues against an expectation that fault movement will disrupt the EBS directly or cause new infiltration pathways that might lead to accelerated degradation of the EBS.

The geologic record, in terms of observed displacements on presently identified faults, provides a basis for inferring potential ground motion. The Paintbrush Canyon fault is expected to govern both the maximum earthquake and ground motion near Yucca Mountain. Large individual fault displacements during the Quaternary have not been identified in the trenches that have been excavated and examined on the Paintbrush Canyon and other faults, providing paleoseismic evidence against large-magnitude ($M \geq 7$) earthquakes. However, the exposures in these trenches do indicate surface rupture, implying associated earthquakes in the magnitude 6 range, perhaps arguably exceeding the maximum background earthquake of local or surface-wave magnitude 6.8 proposed by dePolo et al. (1990). The stability of steep slopes at Yucca

Mountain and the unrotated orientations of heavily varnished colluvial boulders on these slopes provide empirical, though nonquantitative, evidence against severe ground motion from nearby, large-magnitude earthquakes. Peak horizontal acceleration in the repository area is expected to be less than 1g, probably less at the repository depth, and of long wavelength relative to the dimensions of the EBS. Consequently, subsurface ground motion is not expected to damage the EBS sufficiently to precipitate a loss of containment.

In summary, on the basis of the available geologic record of the Quaternary Period, the consensus of the Core Team is that the nature and rates of fault movement or other ground motion are not expected to be such that a loss of waste isolation is likely to occur. The team therefore concludes that a higher-level suitability finding can be supported for this disqualifying condition. Site characterization activities should focus on reducing the existing uncertainties to the levels required for resolving the broader and more stringent requirements of the qualifying condition.

Recommendations for Future Postclosure Tectonics Activities

An important basis for future understanding is confident definition of the set of credible tectonic models that are consistent with the accumulating data and observations. Presently, at least three basic models appear to be about equally consistent with the evidence--(1) a shallow or thin-skinned detachment model, in which surficial structures may not directly reveal the nature of deep extensional faults, probably both strike-slip and normal; (2) a segmented strike-slip model, in which accommodating normal faults may dominate the local deformation and seismicity within a releasing bend; and (3) a normal-fault model, in which a regional domain of deeply penetrating normal faults is interacting with an edge defined by strike-slip faults. Models yet to be identified and those that are currently judged to be less plausible in terms of contemporary tectonics of the area--the caldera and regional-detachment models should still be considered. The implications of these models as to the potentials for faulting, ground motion, volcanism, and deep ground-water flow differ substantially.

Continued exploration for faults and investigations of their history of displacement remains important for both the Preclosure and Postclosure Tectonics Guidelines; trenching, further development of dating techniques, and borehole studies (core and geophysical logs) remain the basic methods. Equally important is the deep geometry of principal structures, including possible detachments. The design of subsurface studies should incorporate the need to evaluate the potential importance of secondary or distributed faulting. Geophysical surveys potentially will provide the most timely and cost-effective data, particularly when supplemented with computer-balanced analyses of fault geometry and insightful geologic judgment. Evaluation of the consistency among current indicators of tectonic conditions--seismicity, in situ stress, and geothermal conditions--should receive continued attention because they provide the linkage of Quaternary history with expectations for the future.

Measurements of ground-motion attenuation with depth and continued development of an empirical data base on the effects of earthquakes on underground structures should be pursued actively to support assessments of potential damage to the EBS. An increased emphasis should be given to design options for eliminating or minimizing such damage, considering the possibility of recurring moderate ground motion as well as strong motion.

Expanded compilation and consideration of an empirical data base on hydrologic effects of earthquakes are recommended, along with continuation of current efforts to simulate these effects by modeling. A possibly important aspect of the empirical data is an assessment of the sensitivity of reported effects to water-table depth.

The cause of the large gradient of the water table from the north and northwest toward the potential repository site, and the consequent sensitivity of that configuration to tectonic disruption by faulting or igneous intrusion, merit intensive study. Of the hydrologic concerns related to postclosure tectonics, this feature probably is the most significant (Freeze et al. in DOE, 1991g), and it is amenable to being addressed by direct action. Currently planned drilling would be relatively shallow and is intended principally to define the water-table configuration more accurately. This is a necessary first step but should be followed by deeper drilling and geophysical studies to test the various hydrogeologic, geothermal, and stress-related causes that have been proposed. The results of this exploration should be incorporated into three-dimensional models, simulating both the existing geologic framework and credible modifications of this framework by tectonic processes, in order to predict possible changes to the local flow system and the position of the water table.

The role of the north-striking fault zones in saturated-zone flow is also recommended for more aggressive study than is currently planned because of their possible susceptibility to effects from renewed faulting or, inversely, to a lack of tectonic activity resulting in mineralization and decreased permeability. Hydrochemical and thermal investigations in the necessary boreholes may prove equally as useful as high-capacity pumping tests.

Volcanism studies should continue as currently planned. Drilling of the remaining uncharacterized magnetic anomalies is important to resolve questions of possible bimodal (basalt-rhyolite) volcanism. Resolution of geochronology issues would decrease the uncertainty of volcanic recurrence rates. Studies of the evolutionary patterns of basaltic volcanic fields will test models of waning volcanism in the Yucca Mountain region. Verification of waning volcanic trends would increase the confidence in the probability of volcanic disruption. Further confidence in the recurrence rate of volcanic events and likely locations of new volcanic centers is desirable, and associated investigations are an integral part of the overall understanding of the tectonic framework of the region. Additional confidence in the probability of volcanic disruption may be provided by quantifying the frequency of occurrence of basalt centers in alluvial basins, along range-front faults and in range interiors. Probabilistic predictions of radiological releases may prove to be a difficult task, but may be bounded through consideration of the area of feeder dikes and establishing the likelihood of basalt magma carrying waste from repository depths to the surface.

Finally, note that in their preliminary assessment of risks associated with 32 potential concerns about the Yucca Mountain site, Mattson et al.

(1991) classed igneous activity at the site barely within the second of their three classes of risk; faulting and hydrologic effects of tectonism fell in their third (lowest-risk) class. If these perceptions are supported by the external review panels soon to report on the coupling of hydrologic, tectonic, and hydrothermal processes, accelerated investigations for the purposes of early identification of potentially disqualifying characteristics of the site would seem not to be warranted. However, the gap between current knowledge of the site and the southern Great Basin and that required for site qualification and licensing is sufficiently large to justify continuation of the currently planned investigations into the effects of tectonism on waste isolation at Yucca Mountain.

The activities just described are generally identified in Sections 8.3.1.8 and 8.3.1.17 of the SCP (DOE, 1988a). Results of this evaluation could be used to emphasize specific activities, and in the case of deeper drilling, represents a recommendation to expand current plans.

2.3.8 HUMAN INTERFERENCE TECHNICAL GUIDELINE: NATURAL RESOURCES

2.3.8.1 Statement of Qualifying and Disqualifying Conditions

Qualifying Condition [10 CFR 960.4-2-8-1(a)]: "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."

Disqualifying Conditions [10 CFR 960.4-2-8-1(d)]: "(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 (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."

2.3.8.1.1 Discussion

The preface to the qualifying and disqualifying conditions for this guideline provides the following guidance: "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 the permanent markers and records required by 10 CFR Part 60, taking into account site-specific factors, as stated in §§ 960.4-2-8-1 and 960.4-2-8-2, that could compromise their continued effectiveness." Note that purposeful mining or retrieval of radioactive waste or materials used in the engineered components of the repository are not included in this analysis. This type of activity is likely to be a planned and calculated intrusion, and the guideline being evaluated is concerned with inadvertent intrusion.

Several words and phrases in the qualifying and disqualifying condition statements require further interpretation to clearly communicate the basis for the evaluation of this guideline. The following interpretations are used for the remainder of this evaluation:

"Likely" is defined in 10 CFR 960.2 as ". . . displaying the qualities, characteristics, or attributes that provide a reasonable basis for confidence that what is expected indeed exists or will occur." From this definition, it may be inferred that will not be likely means displaying the qualities, characteristics, or attributes that provide a reasonable basis for confidence that whatever is under consideration is expected not to exist or not to occur.

"Foreseeable future": This term has specific meaning in the field of economic geology and usually refers to the next few years to 10 years, and occasionally as long as 30 years.

"Presently valuable": This term is equated with the term "economic resource," which is defined as a resource occurring in such concentrations that it is profitable to mine or extract using present technology considering production costs or other costs associated with extraction, refinement, shipping, and sale on the open market.

"Reasonable projections of value, scarcity, and technology": As used in the qualifying condition, this phrase is ambiguous and is not defined in the regulation. Dictionary synonyms, such as moderate or fair, do not help quantify the intention of the requirement, but they may help provide a qualitative understanding.

Reasonable projections will need to be made at several points during site characterization and, likely, during any period under which a license application may be pending in the future. The basis for these projections is likely to rely on the expert opinion of individuals in the field of natural resources and perhaps other technical disciplines.

In addition, the natural resource potential of the site may need to be reassessed at the time a closure decision is considered because closure could be as far in the future as 150 years, a period much longer than current estimates of natural resource potential (foreseeable future) should be extended and considered credible. Definitions, terms, and assumptions will all need to be reviewed by qualified experts to aid in directing the program toward realistic goals and credible natural resources assessments and to establish that regulatory criteria have been defensibly evaluated.

Terminology from 10 CFR 60.21(c)(13) provides further insight into the manner in which this guideline should be evaluated. This section provides the U.S. Nuclear Regulatory Commission's (NRC) requirements for the content of the Safety Analysis Report. The statements of interest are as follows: "...Undiscovered deposits of resources characteristic of the area shall be estimated by reasonable inference based on geological and geophysical evidence. This evaluation of resources, including undiscovered deposits, shall be conducted for the site and for areas of similar size that are representative of and are within the geologic setting. For natural resources with current markets the resources shall be assessed, with estimates provided of both gross and net value. The estimate of net value shall take into account current development, extraction, and marketing costs. For natural resources without current markets, but which could be marketable given credible projected changes in economic or technological factors, the resources shall be described by physical factors such as tonnage or other amount, grade, and quality."

2.3.8.1.2 Background

The long-term waste isolation performance of the site could be compromised via inadvertent drilling, mining, or other exploration or development activities as a result of the presence of economic natural resources or the strong indication of, or perception of, the presence of natural resources. Drilling or mining activities located at the site could lead to a direct loss of long-term waste isolation by the penetration of a drill hole into or near a waste canister or the direct removal of waste via mining. Other exploration, mining, or drilling activities could affect long-term waste isolation indirectly by (1) the creation of new hydrologic pathways along which waste could travel, (2) a loss of the effectiveness of the natural barriers or engineered barrier system (EBS), or (3) the introduction of fluids that could dissolve and transport waste and result in faster travel times or shorter travel paths.

The objective of the Natural Resources Guideline is to ensure that the site or locations near the site have a low enough resource potential that inadvertent drilling, mining, or other invasive exploration activities that could lead to loss of long-term waste isolation would be unlikely to be conducted. All Postclosure Technical Guidelines require compliance with the requirements specified in the Postclosure System Guideline (10 CFR 960.4-1).

2.3.8.2 Approach for Natural Resources Evaluation

2.3.8.2.1 Identification and Basis for Natural Resources Technical Issues

The first step in this guideline evaluation involves the identification of issues related to the natural resource potential of the Yucca Mountain site. They are based, principally, on interpretation of the qualifying condition for the guideline. Also of interest are the results of the previous Environmental Assessment (EA) (DOE, 1986) and pertinent work since the EA that supports issue resolution.

The postclosure natural resources issues were identified by carefully reviewing this guideline condition, information presented in the EA, and the current understanding of the status and plans for associated testing activities. For purposes of this evaluation, ground water is considered as a natural resource. The consideration of the potentially adverse conditions for this guideline are an integral part of the evaluation, although not explicitly tied to this section or the following sections. The scope of this guideline is encompassed by the following issues:

- Technical Issue 1

  Is there evidence of previous mining, exploration, or drilling activities for economic resources at or near the site that may have created significant pathways from the potential underground repository to the accessible environment?

- Technical Issue 2

  Are there ongoing or likely future mining, drilling, or exploration activities to recover presently economic resources outside the controlled area that are expected to lead to an inadvertent loss in waste isolation?

- Technical Issue 3

  Are there resources at or near the site that are likely to be exploited now or in the foreseeable future that could lead to interference activities that would result in radionuclide releases greater than allowed in the Postclosure System Guideline (960.4-1)?

Issues 1 and 2 relate to the disqualifying conditions, and Issue 3 relates to the qualifying conditions for this guideline.

The disqualifying condition (Issue 2) is concerned with present day activities (e.g., mining, drilling, and blasting) conducted outside the controlled area that could affect the waste isolation capabilities of the site. This includes activities we expect to occur in the near future as a result of identified and presently known economic resources located outside the controlled area, but does not include future mining of resources that are presently known. Because these potential activities would be conducted outside the controlled area, a loss in waste isolation could only occur as the result of indirect affects (see Section 2.3.8.1.2). In contrast, the qualifying condition is concerned with assessing the natural resource potential for both those resources that are presently valuable and those resources that are not presently valuable, but which may be valuable in the foreseeable future. The affects of inadvertent human interference could be direct or indirect affects (see Section 2.3.8.1.2).

2.3.8.2.2 Information Required to Resolve Natural Resources Issues

Resolution of Issue 1: Issue 1 can be resolved with an adequate knowledge of past uses of the site. Through evidence gained by geologic mapping, archaeological field investigations, and surveys of records of previous exploration or mining activities, a defensible position concerning this issue can be established.

Resolution of Issue 2: Issue 2 can be resolved on the basis of knowledge of the location of all current mining operations, location of past mining efforts, and possible prospects near the site. In addition, because these locations are outside the controlled area by definition, only indirect effects on waste isolation need to be considered. Indirect effects on long-term waste isolation could result from exploration activities, mining, or drilling. The possible effects include (1) creation of new hydrologic pathways along which waste could travel, (2) loss in the effectiveness of the natural barriers or the EBS, or (3) introduction of fluids that could lead to faster dissolution and transport of waste. Specifically, indirect effects to be considered include (1) introduction of drilling fluids that increase the hydrologic flux or increase rates of dissolution of waste, (2) infiltration of fluids from surface or underground leaching, (3) withdrawal of ground water due to mine de-watering or water production for mine and mill use, and (4) effect related to man-made underground openings (fractures and other openings) created by, for example, open-pit blasting, underground blasting, surface and underground drilling, and large underground block caving.

Resolution of Issue 3: Issue 3 can be resolved if (1) economic natural resources are not expected at or near the site in the foreseeable future; (2) perceived potential for economic natural resources is considered low at or near the site in the foreseeable future; and (3) the effects of development of these economic resources, if present, or exploration for these economic or perceived resources is not expected to lead to a loss of waste isolation. Further, the motivation to explore or develop any possible economic resources must be considered great enough to defeat the purpose of the surface marker system, which would imply the loss of all institutional controls at the site. Evaluations need to consider the general site geology and history, structural geology, geochemical information, geophysical information, past alteration history, past mining or exploration activities, regional geologic and resource development information, and models of economic resource emplacement or formation.

Resolution of Issue 3 will also involve providing additional information before the assessment can be considered complete. First, the volume of material to be assessed for natural resources needs to be explicitly defined. The Site Characterization Plan (DOE, 1988a) called for an evaluation to a depth of 1 km for mineral resources because of established precedent in the geologic literature. Given current economic conditions and projections of natural resource demand in the near future, greater depths will likely need to be considered. Natural resource assessments will, out of necessity, become less detailed with depth, but projections can be accomplished for progressively greater depths, for example, assessments for potential resources that may occur above 1, 2, and 3 km for mineral resources. Second, further definition of the area that is to serve as a basis for comparison (e.g., the Great Basin, the region surrounding Yucca Mountain) is needed before a detailed comparison with the site can be accomplished. The area in which direct or indirect interference activities could affect the proposed repository needs to be more clearly constrained. Third, geologic models of mineral deposits that should be compared to the proposed Yucca Mountain site need to be prioritized and ranked before a detailed comparison is conducted. Consideration of the above factors as related to the oil or gas potential of the site will strongly depend on the likely presence or absence of potential source rocks in the region (See Section 2.3.8.4 for further information).

The potential for economic resources was established as part of this evaluation, including (1) water resources; (2) energy resources, including coal, oil, gas, and geothermal; (3) industrial materials, minerals, and rocks; and (4) precious metals and other metals (e.g., mercury, lead, and copper). If resource potential is high, then the effects of possible exploration or exploitation of these resources need to be evaluated in terms of the Total System Guideline (Section 2.4). Probabilities and consequences of exploratory drilling, at the prescribed areal density or other densities, need to be estimated and release predictions compared with the prescribed standards. Because of the nature of the assessments needed to resolve questions related to this guideline, expert panels and peer reviews are likely to play a key role in the final resolution of this issue.

2.3.8.3 Status of Current Natural Resources Information

2.3.8.3.1 Summary of Environmental Assessment Findings for Natural Resources

In addition to the qualifying condition and two disqualifying conditions, this guideline contains two favorable and four potentially adverse conditions. The findings reported in the Environmental Assessment (EA) (DOE, 1986) are summarized in Table 2-10.

Table 2-10. Summary of Environmental Assessment Findings for Natural Resources (DOE, 1986)

CONDITION	DOE FINDING
FAVORABLE CONDITIONS	
1. No known natural resources that have, or are projected to have in the foreseeable future, a value great enough to be considered a commercially extractable resource.	The evidence indicates that this favorable conditions is present at Yucca Mountain: no present or projected uranium, hydrocarbon, or critical mineral resources have been identified; potential development of ground water for irrigation is not expected because of unsuitable topography and great depth of water table.
2. Ground water with 10,000 ppm or more of total dissolved solids along any path of likely radionuclide travel from the host rock to the accessible environment.	The evidence indicates that this favorable condition is not present at Yucca Mountain: ground water has total dissolved solids less than 300 ppm.
POTENTIALLY ADVERSE CONDITIONS	
1. Indications that the site contains naturally occurring materials, whether or not actually identified in such form that (i) economic extraction is potentially feasible during the foreseeable future or (ii) such materials have a greater gross value, net value, or commercial potential than the average for other areas of similar size that are representative of, and located in, the geologic setting.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: no critical or unique energy, metallic, or nonmetallic resources have been identified in the site vicinity. There is no credible potential for the use of water resources for agriculture.
2. Evidence of subsurface mining or extraction for resources within the site if it could affect waste containment or isolation.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: no evidence of subsurface mining or extraction for resources has been found at the site.

Table 2-10. Summary of Environmental Assessment Findings for Natural Resources (DOE, 1986) (continued)

CONDITION	DOE FINDING
POTENTIALLY ADVERSE CONDITIONS (continued)	
3. Evidence of drilling within the site for any purpose other than repository-site characterization to a depth sufficient to affect waste containment and isolation.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: there has been no drilling at the site except for evaluation for the potential repository.
4. Evidence of a significant concentration of any naturally occurring material that is not widely available from other sources.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: resources in the site vicinity are also found outside the vicinity where they are more abundant and can be extracted more economically.
5. Potential for foreseeable human activities, such as ground-water withdrawal, extensive irrigation subsurface injection of fluids, ties, or the construction of large-scale surface-water impoundments, that could adversely change portions of the ground-water flow system important to waste isolation.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: ground-water development for irrigation is not expected because of unsuitable topography and great depth to the water table. If extensive withdrawal of ground water lowered the water table, improved waste isolation would result because of increases in unsaturated-zone travel times. Limited energy and mineral resources limit the potential for human activities.
QUALIFYING CONDITION	
The site shall be located such that, considering permanent marker 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	Available evidence does not support the finding that the site is not likely to meet the qualifying condition (Level 3): no known valuable natural resources are present, and potential of future natural resources is low; permanent markers are expected to remain effective and discourage future human interference.

Table 2-10. Summary of Environmental Assessment Findings for Natural Resources (DOE, 1986) (continued)

CONDITION	DOE FINDING
QUALIFYING CONDITION (continued)	
that would lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.	

The EA evaluation of the qualifying condition concluded that no known valuable natural resources are present, and no natural resources have been identified at Yucca Mountain that are likely to become sufficiently valuable in the foreseeable future that they would encourage interference activities that could lead to unacceptable releases of radionuclides. Thus, a Level 3 finding was supported. The EA also concluded that good-quality ground water was widely available in the region and at the site and that extensive withdrawal of ground water could actually improve waste isolation performance by increasing the thickness of the unsaturated zone. The EA noted that permanent markers could be installed that could warn future generations of danger at Yucca Mountain. Site-specific characteristics, including aridity and low-population density, are favorable to the preservation of the markers. No factors that would be likely to compromise the effectiveness of the markers were identified or were considered likely to be present (DOE, 1986).

For the first disqualifying condition related to previous exploration and mining, the EA concluded that no significant pathways have been created between the projected underground facility and the accessible environment, which supported a Level 1 finding. For the second disqualifying condition, it was concluded that only shallow mining of industrial materials now exists in the vicinity of Yucca Mountain, and no resources have been identified that would be likely to cause increased mining activities. Further, the conclusion was drawn that there are no ongoing or expected future activities to recover presently valuable natural mineral resources outside the controlled area that could be expected to lead to inadvertent loss of waste isolation, which supported a Level 1 finding.

2.3.8.3.2 Review of Natural Resources Information Obtained since the Environmental Assessment

The EA conclusions were based on information available prior to 1986. Since then, a great deal of information has been gathered on the potential for natural resources at Yucca Mountain and on the possible effects of any development or exploration for natural resources on the waste isolation capabilities of the site. In general, the information obtained since the EA supports and strengthens the findings made in the EA. Much of the information obtained since the EA is discussed in the Site Characterization Plan (SCP) (DOE, 1988a). In Section 1.7, the SCP addresses the potential for natural resources, including metals, energy resources, and industrial minerals and rocks. New information that has become available since the SCP is summarized in the following sections. The sections are divided into discussions pertaining to (1) precious and other metals; (2) coal, oil, and gas resources; (3) geothermal and other energy resources; (4) industrial materials, minerals, and rocks; and (5) water resources.

2.3.8.3.2.1 Precious and Other Metals

Significant additional work on precious and other metals has been completed and reported since the EA (DOE, 1986) and the SCP (DOE, 1988a) were published. General reviews of the potential in the State of Nevada for precious and other metals and summaries of active mine locations, grades, geology, and production statistics are numerous. Several are listed here because they have general or specific relevance to the Yucca Mountain area (e.g., Shaddrick et al., 1988; Stager and Tingley, 1988; Bonham, 1988, 1989; Bedinger et al., 1989; Price, 1989 and 1990; Jones, 1989, 1990, and 1991; NBMG, 1990; Carter, 1990; Bonham and Hess, 1990; Fleming, 1990; NDM-NBMG, 1991; EM&J, 1991). Many papers have been published on ore deposit models for Nevada (e.g., Bonham, 1988), for volcanics (e.g., Sillitoe, 1988), and on tectonic controls (e.g., Price et al., 1987). New geophysical data have become available for the State of Nevada and include maps of regional, residual, and derivative gravity (Saltus, 1988a, b, c); regional three-dimensional analysis of gravity and magnetic anomalies (Blakely and Jachens, 1991); and, a summary of gravity and magnetic studies conducted at Yucca Mountain (Oliver et al., 1991). New dating on ore and ore-related magmatic occurrences and hydrothermally altered volcanics in the Yucca Mountain area has been presented by Aronson and Bish (1987), Jackson et al. (1988), McKee et al. (1990), and Noble et al. (1991). Since the EA, new or modified structural and magmatic models of the Yucca Mountain area are available (e.g., Hamilton, 1988; Ramelli et al., 1988; Carr and Monsen, 1988; Vogel and Byers, 1989; Byers et al., 1989; Scott, 1989b; Schweickert, 1989; Schweickert and Caskey, 1990; Carr, 1990) in addition to those models reviewed in the Postclosure Tectonics section of the SCP (DOE, 1988a).

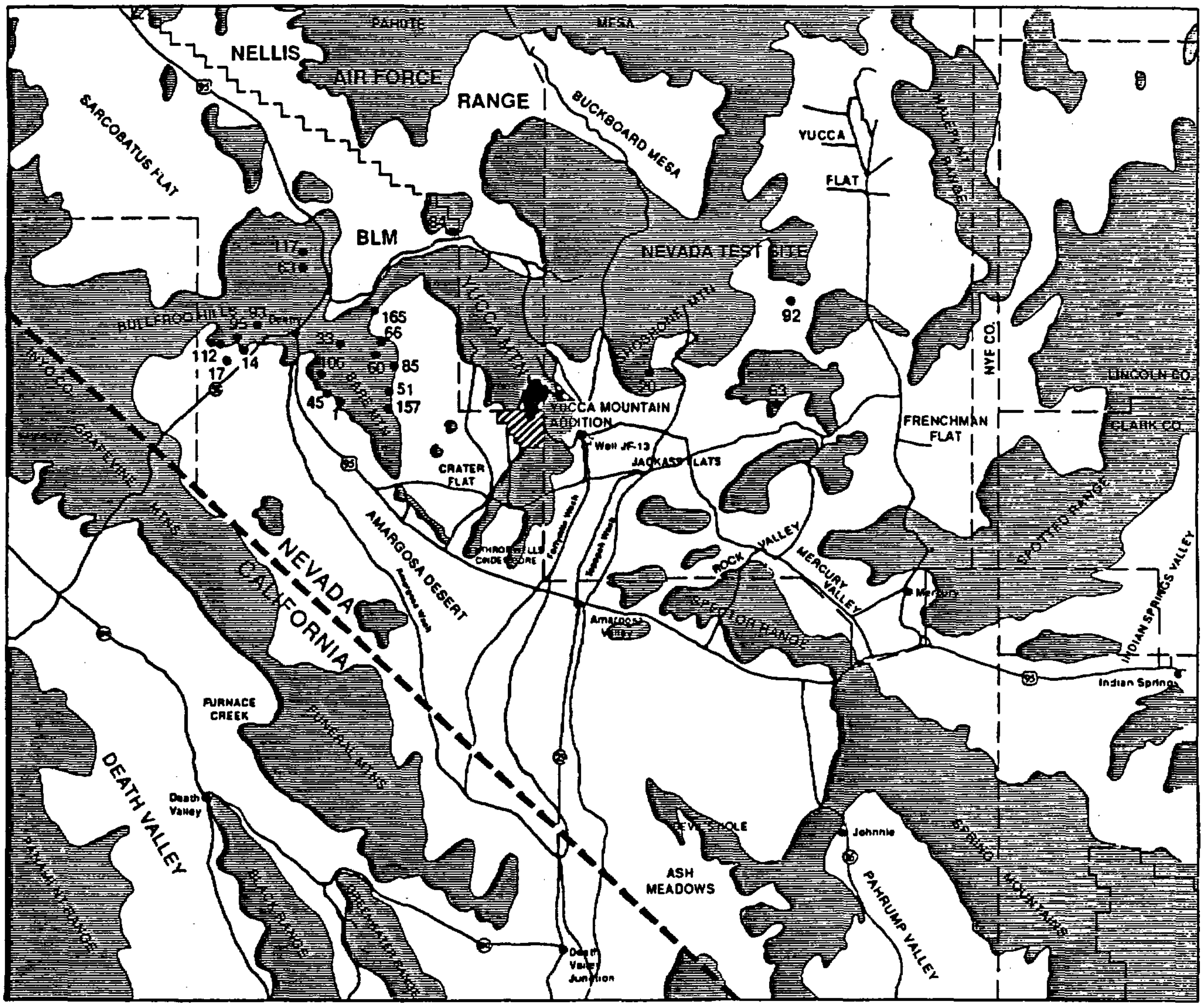
A number of new publications are available on ore deposits and geology of the region of the southwest volcanic field, including the Bullfrog District (Abbot et al., 1989; McKague et al., 1989; Jorgensen et al., 1989 and 1990; Maldonado, 1989 and 1990a,b; Petersen and Ahler, 1990; Weiss et al., 1990; Bergquist and McKee, 1991), the Fluorspar Canyon and Bare Mountain area, inclusive of the Mother Lode, South Zone, West Zone, and Secret Pass Zone deposits (Castor et al., 1989; Greybeck and Wallace, 1991; Lockhard, 1989), and the Sterling Mine (Schafer and Vikre, 1988; Mattson, 1989). Thus, significant exploration activity has been conducted and has resulted in new discoveries in the region of Yucca Mountain since the SCP (DOE, 1988a). These discoveries influence the perceived resource potential of the region, including the Yucca Mountain area. Occurrences of tungsten and gold are reported for southern Bare Mountain (Stager and Tingley, 1988) that were not discussed in the SCP. Active mines, past mines, and key mineral occurrences for the State of Nevada, Nye County, and the Yucca Mountain area have been reviewed by Bonham (1989), Jones (1989), Bonham and Hess (1990), Raney (1990), and Bergquist and McKee (1991). Some present and past mining locations are displayed in Figure 2-2. The numbers on the map refer to the locations and their inferred mineral deposit-type as defined in Bergquist and McKee. The deposit name, reference number, and deposit types are listed in Table 2-11. It should be noted that these deposits are listed without their production statistics. For instance, the Bond Gold Mine has produced several hundred thousand ounces of gold while the Harvey and Thompson mines had little or no production of mercury, but are notable occurrences of mercury mineralization. Detailed maps and other information about these localities are available (Bergquist and McKee, 1991).

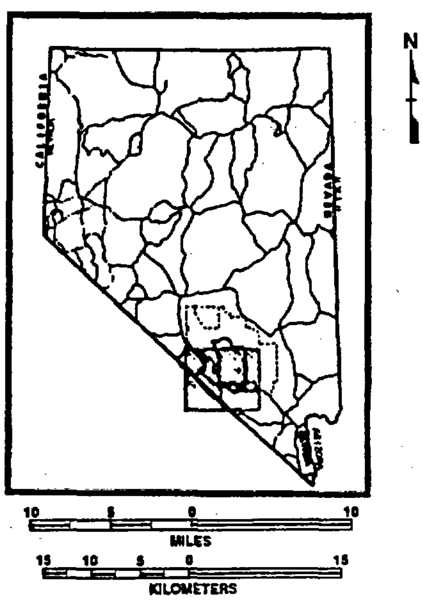
Additional site-specific data include document reviews, new geologic maps, new geochemical data, new regional tectonic and structural information, historical reviews, and resource assessments. This information is discussed below.

The SCP (DOE, 1988a) cited a paper by McKee (1979), who claimed that a high percentage of volcanic-hosted precious-metal deposits in Nevada were located within calderas and not within associated ash-flow sheets. The NRC staff did not agree with this conclusion and requested that Raney (1988a) review some of the basic tenets of the paper. The DOE also requested a review from Price (1988) on both the McKee and Raney papers. Precious metal deposits are known to occur within calderas, outside calderas, and within ash-flow sheets. These reviewers agreed that the statistical percentages cited in McKee were problematical. In addition, Einaudi suggested in Younker et al. (1992) that in comparing precious metal occurrences as a function of host rock lithologies, it would be more germane to compare production statistics from major mining districts than to compare the number of districts. These new reports have little impact on the SCP conclusions because the SCP evaluation was based primarily on site-specific geology, which included geologic mapping, geochemistry, evidence of mineralogy/alteration, and the occurrence of past mining and exploration activities.

New geologic maps available for the Yucca Mountain area include those for Bare Mountain (Monsen et al., 1990), the Nevada Test Site (Frizzell and Shulters, 1990), and a surficial geologic map of the Bare Mountain quadrangle (Swadley and Parrish, 1988). Information drawn from these sources on past mining, exploration, and other activities in the region is presented in Section 2.3.8.3.2.6.

New site-specific geochemical data, together with data reviews, are available (Wycoff, 1988; Mattson, 1988, 1989; Castor et al., 1989). Mattson (1988 and 1989) reviewed available data, while Wycoff (1988) presented geochemical information on mineral claims filed late in the 1980s on the Yucca Mountain site. These claims were considered nuisance claims and were later purchased by the DOE. The proposed Yucca Mountain repository site is located on lands under the control of the Nevada Test Site (DOE), the Nellis Bombing and Gunnery Range (U. S. Air Force), and the Bureau of Land Management (BLM). Castor et al. (1989) assessed the mineral and energy resources of an area known as the Yucca Mountain Addition, which is located on BLM land (see Figure 2-2). This resource assessment was performed to support a land withdrawal request by the DOE, and reported more than 200 geochemical analyses with only a few samples with minor anomalies of gold. The anomalous





Location of the proposed repository

Location of the Yucca Mountain Addition

Location and mineral-deposit type designations for mines near Yucca Mountain

- Hot-spring Au-Ag: 14, 17, 63, 93, 112
- Polymetallic vein: 1, 45, 87, 106, 117, 157
- Hot-spring Hg: 33, 60, 84, 165, 166
- Fe skarn: 20
- Polymetallic replacement: 51, 92
- Fluorite breccia pipe: 85

Figure 2-2. Map showing the location of the Yucca Mountain Addition and some past and present mining areas discussed in the text (modified after Bergquist and and McKee, 1991).

Table 2-11. Deposit-Types and Reference Numbers for Figure 2-2

Hot Spring Au-Ag		Polymetallic Vein		Hot Spring Hg	
14	Bond Bullfrog	1	Arista	33	Daisy
17	Bullfrog	45	Gold Ace	60	Harvey
63	Horn Silver	87	Mayflower	84	Mammoth
93	Montgomery-Shoshone	106	Oasis	165	Thompson
112	Original Bullfrog	117	Pioneer	166	Tim Top
		157	Sterling		
Iron Skarn		**Polymetallic Replacement**		**Florite Breccia Pipe**	
20	Calico Hills area	51	Goldspar	85	Mary
		92	Mine Mountain		

samples were collected more than 4 km from the primary repository area, and the largest anomalies were 0.023 ppm gold and 0.5 ppm silver. Castor et al. (1989) also reported the results of lineament analysis, satellite imagery, and geochemical and mineralogical comparisons with known mineralized areas or deposits in the region in an effort to locate alteration and anomalous zones comparable to those found near the Yucca Mountain site. The Castor et al. (1989) report states that there are no identified surface or near-surface mineral resources within the Yucca Mountain addition; the potential for base metals and precious metals was assessed to be very low. Because the Castor et al. (1989) study was conducted for purposes of land withdrawal, the study did not provide a detailed basis on which to assess resources at depths greater than several hundred meters. In addition, Castor et al. (1989) focused the main detail of their report on the evaluation of precious metals. Studies are planned that will provide more detailed information and further assessments and evaluation of all the potential mineral resources of the site (See Section 2.3.8.4).

New information on structural models in the Yucca Mountain region are also available and, in general, these have been reviewed in Sections 2.3.7 and 3.3.3.4 of this report. These sections describe classical Basin-and-Range-style faulting (i.e., steep normal faults bounded by range front faults), pull-apart basin models, high-angle faults, which have been rotated to low angles, and various detachment style faulting models. The SCP may have over-emphasized the importance of detachment models in ore genesis. For example, Einaudi Comment 19 (in Younker et al., 1992) states that, with regard to epithermal precious metal deposits, "In contrast, 'detachment type' precious metal deposits have neither proved to be important (in relative terms) nor proved to be easily documented as fundamentally different types of deposit......It can be pointed out that, although the literature on recent discoveries in the area of Bullfrog Hills and Fluorspar Canyon have emphasized the 'detachment model' (e.g., Jorgensen et al., 1989), the discoveries of gold deposits near Yucca Mountain probably were made using standard observational and analytical approaches developed for the general class of epithermal precious metal deposits in volcanic rocks." Einaudi further states in Younker et al. (1992) that "Structural controls in volcanic-hosted epithermal deposits tend to be steep, but there are numerous examples of vein systems with relatively shallow dips, especially in extended terrains where early steep normal faults that have served as the ore-fluid conduits have been rotated on younger faults (e.g., as low as 30 degrees at Goldfield (Ruetz, 1987) and as low as 15 degrees at Tonopah (T. B. Nolan, in Dreier, 1984)." All of these models will need to be carefully evaluated in light of their significance to possible ore-forming flow conduits and the potential for hidden mineral deposits at the Yucca Mountain site.

Furthermore, the SCP emphasized new types of deposits discovered and mined in the last two decades. It will be necessary to establish a preliminary ranking or relative importance of these new types of deposits. New types of deposits include disseminated gold deposits in calcareous sedimentary rocks (e.g., Carlin-type gold deposits) that have been the focus of recent gold exploration activities in the Basin and Range because they are the most numerous and economically important. The discovery and exploration history of the Carlin deposit has been reviewed by Coope (1991). These deposits may not be very important in the area of Yucca Mountain because of the depth to the basement (greater than 3-4 km) according to Einaudi, in Younker et al. (1992). Other important types of deposits are epithermal disseminated gold-silver deposits in volcanic rocks (e.g., Round Mountain, Rawhide, and Paradise Peak deposits). The identification, ranking, and comparison of ore-forming systems to site-specific data will be very important in assessing the potential for undiscovered deposits at the site.

The Site Characterization Plan (DOE, 1988a) stated that "Exploration and production of precious metals has recently centered around disseminated deposits that are not produced for base metals." While this statement is still generally true, it should also be pointed out that numerous gold discoveries have been made in districts that historically have been base metal producers and that copper-gold deposits have received considerable attention as a result of these discoveries. Discoveries in the Basin and Range include (1) the Fortitude gold skarn in the Battle Mountain porphyry copper district (Myers and Meinert, 1991); (2) the McCoy (Au) and Cove (Ag) deposits south of Battle Mountain (Brooks et al., 1991); (3) the disseminated gold deposits in sedimentary rocks (e.g., Star Pointer) on the immediate fringe of the Ely porphyry copper stocks (Einaudi, in Younker et al., 1992); and (4) the Parnell gold shoot in Cu(Au) skarns of the Bingham district (Einaudi, in Younker et al., 1992). This information makes it clear that a careful evaluation will be needed before final conclusions about the resource potential of the proposed site are made.

2.3.8.3.2.2 Coal, Oil, and Gas

The potential for oil, gas, coal, and tar sand resources were all discussed and reviewed in the SCP (DOE, 1988a). The potential for these energy resources was considered low to very low in the Yucca Mountain region.

A number of studies concerning the oil potential of Nevada have been published since the EA and SCP and are reviewed in the following paragraphs.

New summaries of the oil and gas exploration, production, and geologic occurrences in Nevada have been published (Garside et al., 1988; Peterson, 1988; Foster et al., 1989). New production and occurrence information is available (NBMG, 1988; Ehni and Evans, 1989; Purkey, 1989, 1990; Fritz 1984, 1987, 1988, and 1989; and Brady, 1989). Geologic and production information is available for specific oil fields located in Nevada (e.g., Read and Zogg, 1988; Veal et al., 1988; and Hulen et al., 1990). A pre-Mesozoic palinspastic reconstruction for the eastern Great Basin has been published (Levy and Christie-Blick, 1989) and new structural and paleogeographic information on facies boundaries for southern Nevada are available (Stevens et al., 1991).

Successful exploration for oil and gas in the Great Basin region is strongly influenced by the location of generation sites in time and space (Poole et al., 1983; Poole and Claypool, 1984). This contrasts with exploration in more mature productive basins in the U.S., where the position of generation sites is well established and exploration is focused on the location of favorable reservoir rock and trapping conditions. For this reason, the assessment of the potential for oil and gas resources for the Yucca Mountain area should be made initially by developing models of generation rather than models of entrapment (French, in Younker et al., 1992). Models of hydrocarbon generation in Nevada are of two basic categories: generation prior to the onset of the Basin-and-Range Orogeny and generation since the onset of the Basin-and-Range Orogeny.

In Nevada, total oil production has exceeded 26 million barrels with greater than 11 million barrels from the Grant Canyon Field (Purkey, 1989). All commercially producing fields in Nevada contain the following key elements: (1) close proximity to adequate organic-rich source rocks; (2) appropriate thermal history applied to those source rocks; and (3) Tertiary block faulting with appropriate stratigraphic or structural seals (French, in Younker et al., 1992). Reservoir rocks are carbonates and ash-flow tuffs (DOE, 1988a). All fields in the region are situated in Neogene Basins, beneath a sequence of Miocene-Recent valley fill. Some of the oil fields in Nevada are in close proximity to intrusives (Hulen et al., 1990), which may contribute to reservoir quality and generation of hydrocarbons. However, all commercial fields in the region are located in basins of Miocene-Pliocene age that formed as the result of block faulting during the Basin-and-Range Orogeny (French, in Younker et al., 1992). Different kinds of oil plays (i.e., prospects) in the eastern Great Basin have also been reviewed by Peterson (1988), including unconformity plays, Upper Paleozoic plays, and pre-Devonian plays. In addition, it has been suggested that significant production in Nevada is closely related to a Mesozoic thrust fault system in the east-central part of the state (Scott and Chamberlain, 1987c). However, the importance of the thrust belt is difficult to establish; it is possible that the location of the fields is more directly influenced by the distribution of source rocks deposited in the Antler foredeep and lacustrine basins of Cretaceous and early Tertiary age (Poole and Claypool, 1984). Finally, successful oil exploration in Nevada has been troubled by recoverable reserves that are difficult to quantify, high transportation costs, and elusive traps or complex geology (Foster et al., 1989). However, many exploration geologists remain enthusiastic about the potential for further oil discoveries in Nevada (Fritz, 1987, 1988, and 1989).

The current debate over models of oil plays that range from fault-block models to overthrust models (Fritz, 1988 and 1989) is germane to the evaluation of the resource potential at Yucca Mountain. Keener (1986), Chamberlain (1987 and 1989) and Scott and Chamberlain (1987a,b) postulate that areas with high potential for oil and gas are characterized by Devonian carbonates overthrust on Mississippian source rocks. Similar models have been suggested for the Nevada Test Site (NTS) area (Aymard, 1989). A variation of the overthrust model has been proposed for the Eleana Range and the Yucca Mountain area by Chamberlain (1991). In this hypothesis, over-mature Mississippian strata are overthrust on submature Mississippian source rocks. The model is believed to be based on a specious interpretation of the Diamond Range near Eureka, Nevada. There is no conclusive evidence that any production in the Great Basin is from overthrust structures (Allcott, 1991) and the comments of Flanigan (1986) indicate that there is not a consensus about the validity of the overthrust model. The fault-block model apparently best describes the accumulations found to date in the province. Field limits are controlled by normal faults and fault-block geometry and accumulations are confined to basins that are defined by Basin-and-Range normal faults. The various models need to be tested for applicability to the Yucca Mountain area by examining model compatibility with known geologic conditions at Yucca Mountain and with known occurrences of oil in Nevada.

Reviews of the thermal maturity of Paleozoic rocks in the vicinity of Yucca Mountain (Bare Mountain, Striped Hills, and Calico Hills) (DOE, 1988a) show conodont maturation indices (CAI) typically >4, but with a few lower (e.g., 3), and thus, are at or about the upper end of the wet/dry gas window. Drillhole UE-25 p#1, located approximately 2 km east of the proposed site, intersected Silurian dolomites at a depth of 1,244 m; these dolomites have a CAI of 3 (Carr et al., 1986). This drill hole is located in a section of Paleozoic carbonates and Tertiary tuffs uplifted presumably as a result of Tertiary faulting. Three boreholes have penetrated ash flows at Yucca Mountain to a depth of approximately 6,000 ft with the Paleozoic section believed to be several hundred feet to 2,500 ft below that. A 1909 newspaper account reports that oil seaps occurred at Indian Springs and north of Rhyolite (Stoffle et al., 1990b), but no later publications or geologic reports can be found to verify these occurrences.

Aymard (1989) and Zhang (1989) report new unpublished data of Chamberlain and Nitchman on the thermal maturation of rocks in the vicinity of the Nevada Test Site and Yucca Mountain. These data were obtained by a variety of methods, and generally agree with previous data collected near Yucca Mountain, but strongly contrast with the regional information at such localities as Syncline Ridge and Shoshone Ridge. At Calico Hills, conflicting data are reported with thermal maturity ranging from oil to dry gas windows. These thermal-maturation data may be important for evaluating rocks at depth and determining the most appropriate generation-migration-accumulation model for the Yucca Mountain area. Additional thermal-maturation data may need to be collected to verify the data presented in Aymard (1989). In addition, generation potential of the various source rocks at different states of maturity needs to be determined so that meaningful conclusions can be drawn about the quantity of hydrocarbons that has been rendered for given levels of maturity.

Very recent wildcat drilling has occurred and is planned in the region of Yucca Mountain. A well was drilled by the MYJO Oil Corporation, the Coffer well, located in Section 31, T. 10 S., R. 48 E., 1,980 ft from the south line and 666 ft from the east line (Mattson, 1991). This well is located approximately 20 miles northwest of the Yucca Mountain site and reached a total depth of 3,877 ft, all within ash-flow tuffs of the volcanic section. The hole was abandoned with no reported shows (i.e., minor subeconomic occurrences) of oil or gas. Because information about private operations are proprietary, this information should be considered tentative until further detailed information can be obtained. Three additional wells south of the town of Amargosa Valley and southeast of the Yucca Mountain site (Czarnecki, 1991a) are planned in 1991. The holes are to be completed in Paleozoic carbonate rocks. The oil or gas potential on which these wells were sited is unknown. Progress will be monitored, and results may prove useful in understanding the hydrocarbon potential of the Paleozoic rocks that underlie Yucca Mountain.

Exploration plays in the Basin-and-Range Province may be organized into Post-Miocene and Pre-Miocene based on the time of accumulation. Post-Miocene plays are those directed toward finding accumulations that have developed since the onset of the Basin-and-Range Orogeny. There is no connotation of source or reservoir rock objectives. This category includes the unconformity play as described by Peterson (1988). The exploration targets of pre-Miocene plays are accumulations that predate the beginning of the Basin-and-Range Orogeny and thus have remained intact through the deformation of that event. Exploration focuses on Paleozoic strata that has been deformed by Mesozoic-age fold and thrust-fault structures, although post-Miocene changes to these structures is conceivable. Most exploration targets of the Upper Paleozoic and pre-Devonian plays of Peterson (1988) are in this category. Of the oil found to date in Nevada, all fields except the Currant Field in Railroad Valley and some minor production in Pine Valley clearly belong in the post-Miocene category. There is no production from a pre-Miocene accumulation that can be identified.

The petroleum potential of Yucca Mountain is considered low at this time. The possibility of a Railroad Valley-type fault-block accumulation near Yucca Mountain is small because of the apparent lack of a Neogene generation site. The possibility exists that a post-Miocene accumulation resulting from remigration from a pre-Miocene trap is present in the vicinity. Although improbable, this possibility merits additional investigation. Pre-Miocene targets in the form of overthrust play models have been proposed for the area near Yucca Mountain and in eastern Nevada (Chamberlain, 1991). Allcott (1991) concluded that overthrust models do not provide a reasonable explanation for oil and gas plays in Nevada. In addition, the entire state of Nevada was evaluated for petroleum potential by Garside et al. (1988). They concluded that southern Nye County has a low potential for petroleum resources, and none of the areas they designate as having high to moderate petroleum potential are within approximately 60 to 80 miles of Yucca Mountain. Finally, the Yucca Mountain area was assessed for its oil and gas potential by the Nevada Bureau of Mines and Geology

(NBMG), for the purposes of land withdrawal and was rated as having a low potential for oil and gas (Castor et al., 1989). Thus, the findings presented in the EA are consistent with the newly available data and with the conclusions presented in the SCP.

2.3.8.3.2.3 Geothermal and Other Energy Resources

The potential for geothermal energy and uranium resources was reviewed in the SCP (DOE, 1988a) and considered very low in the Yucca Mountain region. New geochemical data is available on potential uranium resources and an assessment has been made that the potential for this resource is very low (Castor et al., 1989). Geothermal gradients in the southwestern United States have been reviewed by Nathenson and Guffanti (1988), and geothermal resources in Nevada have been reviewed by Hess and Garside (1989, 1990). Several new reports on local temperatures of springs and wells in the region are available (e.g., Dudley, 1990a, b) and complex hydrologic flow is postulated for the carbonate aquifer (Sass et al., 1988; Dudley, 1990a, b; Czarnecki, 1990b). The potential for medium- or high-temperature geothermal resources in the Yucca Mountain area is considered very low. Low-temperature geothermal resources are ground waters that maintain average annual temperatures above average regional ambient temperatures and can be used for home or industrial plant heating. Although the Yucca Mountain area has ground waters with average annual temperatures slightly above regional average ambient temperatures, they are considered unlikely candidates for development because of the high cost of development. Deep drilling and large pumping lifts are required relative to the potential benefit of the resources (DOE, 1988b). Castor et al. (1989) also stated that the Yucca Mountain addition "...does not appear to have potential for the discovery of geothermal resources."

2.3.8.3.2.4 Industrial Materials, Minerals, and Rocks

The potential for industrial materials, minerals, and rocks was discussed and reviewed in the SCP (DOE, 1988a). The potential for these resources was considered to be very low in the Yucca Mountain region. Active mines in the region of Yucca Mountain and annual production figures are reported in NDM and NBMG (1991) and Castor (1989, 1990). Clays, zeolites, and basaltic pumice are mined in the region (Eyde and Shelton, 1991; DOE, 1988a). Fluorspar has been mined in the recent past. Castor et al. (1989) assessed the Yucca Mountain Addition as having a very low potential for industrial minerals and materials. The remainder of the Yucca Mountain site also has very low potential for these resources (DOE, 1988a). The conclusions presented at the time of the SCP on industrial materials, minerals, and rocks have not changed.

2.3.8.3.2.5 Water Resources

It has long been recognized that ground-water resources underlie the Yucca Mountain site at depth. This, however, is not a remarkable occurrence, as the same good quality ground-water resources underlie the entire region. The resource in much of the surrounding region is more attractive with regard to exploitation than the water under Yucca Mountain. This is true for several reasons: (1) the water table at Yucca Mountain and south and east of the mountain is fairly uniform at 730 m elevation; a well drilled at a topographic low, such as along Fortymile Wash in a location similar to J-12 and J-13 wells, would require less drilling to reach water; (2) these same wells drilled at topographic lows would require less pumping lift and therefore less expense to acquire the same amount of water; (3) drilling for water is very unlikely because agriculture is not feasible on Yucca Mountain due to rugged terrain, high topographic relief, and lack of arable soils. In summary, Yucca Mountain is an impractical prospect as a target for drilling for water resources compared to the many topographic lows in the surrounding region.

2.3.8.3.2.6 General Resource Information

Historical information is available from archaeological and historical surveys of the region (e.g., Pippin, 1984, 1986; Pippin et al., 1982; DOE, 1986; Raney, 1989; Stoffle et al., 1990a,b). Past mining, historical, and exploration activity has been summarized by Mattson and Matthusen, 1992. Extensive geologic maps or geologic summaries have been compiled for the area and have commonly reported past mining and exploration activity, water resources development or drilling activity, or other previous activities (Lipman and McKay, 1965; Lipman et al., 1966; Cornwall, 1972; Cornwall and Klienhampl, 1961, 1964; Bell and Larson, 1982; Benson et al., 1983; Smith et al., 1983; Smith and Tingley, 1983; Scott and Bonk, 1984; Bedinger et al., 1984, 1989; Tingley, 1984; Maldonado, 1985; Benson and McKinley, 1985; Frizzell and Shulters, 1990; Oliver et al., 1991). Geologic reports that discuss past exploration and mining, exploitation of water resources, and bibliographic surveys are numerous and are best summarized by the reports of Ransome (1907); Ball (1907); Lincoln (1923); Kral (1951); Cornwall (1972); Garside and Schilling (1979); Trexler et al. (1979); Harris et al. (1980); Bell and Larson (1982); Pippin et al. (1982); Quade and Tingley (1983); Benson et al. (1983); Garside (1983, 1984); Scott and Bonk (1984); Pippin (1984); Klienhampl and Ziony (1984); Maldonaldo (1985); DOE (1986, 1988a); Stager and Tingley (1988); Bonham (1989); Raney (1989, 1990); Castor et al. (1989); Wetzel and Raney (1987); Stoffle et al. (1990a,b); Linehan (1991); NDM and NBMG (1991); Tingley and Newman (1991); and Bergquist and McKee (1991). Potential deposits to be evaluated in a resource assessment of the Yucca Mountain site can be gauged by considering deposits of strategic or critical importance in the State of Nevada (Lowe et al., 1985). The results of the search of mining claim activities, together with a review of the literature, indicates that there is an extremely low probability that past mining or exploration produced significant pathways from the proposed repository to the accessible environment (Mattson and Matthusen, 1992) and thus, strengthens the findings made in the EA.

2.3.8.3.2.7 Permanent Markers

The qualifying condition for this guideline requires that permanent markers be considered as part of the system of controls used to reduce the potential for human interference with the radioactive waste. Previously published reports on markers were not evaluated when the EA was published. Kaplan (1982) evaluated several ancient man-made monuments, including the pyramids of Egypt, Stonehenge in England, the Nazca Lines in Peru, Serpent Mound in Ohio, the Acropolis in Greece, and the Great Wall of China. Each monument was described in detail including construction materials, who constructed it and when, why it was constructed, current state of preservation, history of the structure, and relevance to a repository marker system.

On the basis of these investigations, Kaplan (1982) developed marker system design. The three major components included a series of monoliths defining the perimeter of the repository site, an earthwork in the form of the hazardous material warning symbol, and a marker at the center of the site. The perimeter markers are to be single-piece construction, megalithic, and composed of a hard, dense nonporous rock, such as granite or basalt. They should be spaced so that a person could stand at one marker and see the markers on either side, and have a message inscribed that indicates a dangerous substance is buried and that more information is available in the center marker. The earthwork should be incorporated if the decision is made that the markers should be visible from the air. The interior marker should be a mound with a buried vault, which could include detailed information on the repository.

Berry (1983) reviewed probable long-term performance of materials that might be used in the marker systems for radioactive waste isolation sites. Titanium, Hastelloy C-276, SYNROC B, and sintered Al_2O_3 (synthetic sapphire) are suggested as marker materials that would survive in a moist, temperate climate with minimal deterioration. Berry (1983) disparages the use of natural rock, even though his advocacy of SYNROC is based upon the survival of natural rock analogs. Kaplan (1982) also notes that stone has survived more often than metal, because metal has often been scavenged, vandalized, or recycled while large stones have been left in place. Whichever type of surface marker or earthworks are used, care should be taken to avoid configurations that could significantly increase infiltration into the repository block.

A Human Interference Task Force (1984) compiled findings related to long-term human communication through use of permanent markers and widely disseminated records. This approach allows various steps to be taken to provide multiple levels of protection against loss, destruction, and major language or societal changes. They advocated many of the site markers proposed by Kaplan (1982) and suggested various ways of making the site discernible by present day remote-sensing techniques. Information dissemination was advocated with storage of the distributed material in many locations. It should be noted that the EPA has indicated that active institutional controls should not be assumed to be effective for more than 100 years after disposal [40 CFR 191.14(a)]. Overall, redundancy is proposed by the task force as the main method of ensuring that the message is passed on for the 10,000-year period.

2.3.8.3.3 Status of Natural Resources Information

In general, new information has substantially reinforced conclusions presented in the EA. The following addresses new information for each of the issues raised in Section 2.3.8.2.1:

<u>Issue 1</u>: Is there evidence of previous mining, exploration, or drilling activities for economic resources within the site that has created significant pathways from the projected underground repository to the accessible environment?

Resolution of this issue requires an assessment of the previous mining and exploration activities in the region. This information is now available and supports a conclusion that no previous exploration or mining ventures have occurred within the site boundaries that could have created significant pathways from the proposed underground repository to the accessible environment. No further work is needed to assess the suitability of the site with regard to this issue.

<u>Issue 2</u>: Are there ongoing or likely future mining, drilling, or exploration activities to recover presently economic resources outside the controlled area that are expected to lead to an inadvertent loss in waste isolation?

Resolution of this issue requires an assessment of ongoing or likely future mining (i.e., known deposits), exploration, or exploratory drilling activities in the region outside the repository controlled area. On the basis of the extensive literature on this subject, the Core Team has concluded that no likely future mining, drilling, or exploration activities will be located close enough to the site that the activity could result in an inadvertent loss in waste isolation. No further work is needed to assess the suitability of the site with regard to this issue; however, the team believes that a DOE position on this issue should be developed and defended.

<u>Issue 3</u>: Are there resources at or near the site that are likely to be exploited now or in the foreseeable future that could lead to interference activities that would result in radionuclide releases greater than allowed in the Postclosure System Guideline (960.4-1(a))?

This issue is not yet considered resolved, although new information strengthens the conclusion presented in the EA. Uncertainties exist due to limited downhole geochemical data, no geochemical information on soils, and limited geochemical/petrological information on anomalous rocks (such as fault zones or localities above minor induced polarization anomalies). The potential for oil and gas needs further assessment. In addition, the economic potential of the Yucca Mountain site in comparison to rocks of similar geologic settings or in comparison to the surrounding region needs further evaluation.

The development of water resources at the site is considered to be unlikely. Because of the great depth to water resources under Yucca Mountain, the availability of good-quality water in the region at shallower depths, the lack of arable soils, and the lack of any presently projected activities (e.g., mining or industrial development), it is judged improbable that extracting ground water could indirectly or directly affect the waste isolation capabilities of the site. No further studies for water resources are recommended.

All available information indicates that a marker system can be developed that is capable of warning future generations of the hazardous materials that would be contained in a repository at Yucca Mountain. Additional confidence is provided by work by Whitney and Harrington (1988 and in preparation), who have studied dark varnished, colluvial deposits of large, angular boulders that form linear stripes perpendicular to contour at Yucca Mountain, Skull Mountain, and Little Skull Mountain. Dating of desert varnish on these deposits by the cation-ratio method provides estimated minimum ages of 170,000 to 760,000 years for Yucca Mountain. This indicates that the deposits have been stable for long periods. Minor amounts of erosion on the stream channels between the deposits (less than 1 m) indicate stream erosion rates on the order of less than 1 cm per thousand years (Whitney and Harrington, in preparation). This provides strong evidence that not only are monoliths capable of remaining in place for long periods of time, but also that weathering and erosion are minor in the area.

2.3.8.4 Conclusions and Recommendations for Future Natural Resource Activities

Qualifying Condition: The consensus of the Core Team is that available evidence continues to support the lower-level suitability finding (Level 3). This evidence suggests that natural resources at or near the Yucca Mountain site are unlikely to encourage interference activities that would lead to radionuclide releases. However, additional information is needed to strengthen this conclusion and support the higher-level suitability finding for this qualifying condition.

Disqualifying Condition: The consensus of the Core Team is that new information is extremely unlikely to indicate that either (1) previous resource exploration or extraction activities at the site created significant pathways between the projected underground facility and the accessible environment or (2) resource exploration or extraction activities for presently valuable resources outside the controlled area would be expected to lead to inadvertent loss of waste isolation. On this basis, the team consensus is that evidence is sufficient to support higher-level suitability findings (Level 2) for both disqualifying conditions.

Discussion

Several additional tasks are recommended before an adequate basis would be available to support a higher-level suitability finding for the qualifying condition. These tasks are as follows:

Evaluation of Oil and Gas Potential: As indicated in Section 8.3.1.9 of the SCP (DOE, 1988a), the potential for oil and gas resources at the Yucca Mountain site requires more investigation. A draft outline for this work (Activity 8.3.1.9.2.1.4 -- Assessment of Hydrocarbon Resources at and Near the Yucca Mountain Site) has been prepared. This outline is comprehensive but should be reviewed and reorganized so that studies are conducted in a manner to maximize information benefits and cost effectiveness. Recommended investigations are organized below into a stepwise sequence so that work completed is evaluated and the justification established for conducting the next study. Consequently, investigation steps are presented in order of decreasing importance as follows:

1. Test for the presence of a viable source rock that has generated and expelled, or is generating and expelling, significant amounts of hydrocarbons. If it can be established that a viable source rock is not present, further evaluation is unnecessary. To do this:

   - Investigate the stratigraphic section for potential source rocks other than the Eleana Formation, for example the Bird Spring equivalent and Horse Spring Formations

   - Develop a generation index of potential source rocks by conducting pyrolysis on samples that are at various stages of maturity.

   - If viable source rocks are present in the section, determine their areal distribution.

2. If a viable source rock is present, determine its thermal history to identify generation sites in time and space. Much of the data needed for this will be obtained during Step 1, above.

3. Evaluate existing production in the Basin-and-Range Province to determine the applicability of various exploration concepts. In particular, it would be valuable to know if remigration has occurred from older fold-thrust structures to present accumulations. These findings can then be used to determine a hierarchy of exploration concepts and estimate the probability of potential within those concepts for the Yucca Mountain area.

4. Prepare a structure map contoured on the base of the volcanic section to identify possible generation sites and to help assess the likelihood of future exploration activity. This mapping should incorporate interpretations of appropriate paleogeologic and geophysical data. The usefulness of existing geophysical data, especially seismic data, should be reviewed and new surveys using recent technology considered as appropriate.

In addition to the investigations listed above, it is important to establish the means of monitoring and regulating drilling activity. In addition to previous plans, drilling executed for the purpose of site characterization should utilize gas detection devices, and dipmeter logs should be run where Paleozoic strata are penetrated. It is also important to establish a policy designed to take advantage of industry exploration and government-sponsored drilling in the area. For example, subsidizing source-rock analysis or dipmeter logs at appropriate drill sites could contribute to evaluation of the qualifying condition.

Most of the activities described in this section fall within the planned site characterization program (e.g., Study Plan 8.3.1.9.1--Natural Resource Assessment of Yucca Mountain, Nye County, Nevada). However, recommendations are made to emphasize or expand upon certain activities.

Mineral Resources Observational Data Base and Other Data Needs: The most important future work includes (1) the analysis of hydrothermal flow paths based on the detailed consideration of structure, lithology, wall-rock alteration features, and the occurrence of fractures/veinlets/veins, (2) surface and down-hole geochemistry, and (3) an identification, ranking, and comparison of ore-forming systems with the site-specific observational data base collected for the Yucca Mountain site. The term "ore-forming systems" is emphasized and used here in the context of conceptual ore-deposit types that are attributed to various ore-forming systems in contrast to an approach based on specific commodity types.

New observational data should enable the construction of map views, overlays, and cross sections that display information on (1) wall-rock alteration, (2) vein and veinlet attitudes, (3) vein and veinlet mineralogies, (4) sulfide and oxide mineral distribution, and (5) primary and pathfinder element and element ratio maps. In the SCP (Section 1.7.1.2.3), it was stated that rock alterations observed at the Yucca Mountain site are not the same mineral assemblages commonly found in epithermal mineral deposits. Some minerals do occur at Yucca Mountain that also occur in precious metal deposits, although the array of different types of wall-rock alteration styles commonly found in such deposits are not known to occur at the Yucca Mountain site. Collection of the observational data base will allow for more detailed and thorough assessments of rock alterations at the Yucca Mountain site.

Additional geochemical sampling will need to be conducted to fully evaluate the potential for natural resources. This includes sampling, with appropriate geochemical detection limits, for such elements as gold, silver, uranium, and mercury. Further discussions of the geochemical elements to be sampled and rock samples to be collected and analyzed has been presented in the SCP, Section 8.3.1.9 (DOE, 1988). Geochemical soil survey and rock sample information will be important in assessing the potential for undiscovered deposits and help provide a basis on which to fully assess the mineral resource potential of the site. To date, no soil geochemical surveys are available for the proposed site. A large amount of information is currently available from surface outcrops (e.g., DOE, 1988a; Castor et al., 1989). However, few geochemical analyses are available from rock samples that come from areas of "anomalous" rock. In this case, "anomalous" rock refers to rock samples that could be obtained from fault zones, gouge zones, breccia zones, altered areas, or other rocks whose occurrence is limited in the area. Preparation of maps and overlays of chemical data can yield important information on structural trends. Such maps can also assist in definition of prospects by highlighting geochemical anomalies or anomalies in pathfinder elements (i.e., a mercury anomaly could be indicative of a gold deposit), or by identifying areas of alteration that could represent an ore deposit.

No significant gravity or magnetic anomalies have been identified, but for areas that are identified as having minor geophysical anomalies (e.g. induced polarizations anomalies) detailed petrological or geochemical sampling may be required. (See Section 1.7 (DOE, 1988a) for additional discussion). Rock alteration maps may prove valuable when used in conjunction with the geological, geochemical, and geophysical surveys.

Very few of the cored drill holes at or near Yucca Mountain have been sampled geochemically for the express purpose of assessing natural resource potential. Available information on geochemistry and petrology has been reviewed by DOE (1988a) and Mattson (1991). Additional downhole information (geochemical and petrological) will be needed on new cored holes at the proposed site, and previously drilled holes may need to be sampled as well. However, much of the core from these holes has been used for other purposes and coverage would be of variable quality and quantity. All of the cored holes have been petrologically examined, and reports on their petrology published. Future cored holes should be used to produce rock alteration maps and can serve to identify areas that may require further detailed work. Areas that have been identified as containing alteration that occurs in some ore-deposit types in the Basin-and-Range Province should be carefully examined. These areas have been partially identified in the Site Characterization Plan (DOE, 1988a) and in Castor et al. (1989). Downhole petrological and geochemical data will help provide a basis on which to fully assess the mineral resource potential of the proposed site.

Comparisons of the Proposed Site with Known Deposits in Similar Settings: Utilizing the above geologic, geochemical, and petrological information, systematic comparisons of the proposed site with known deposits in the region that occur in similar geologic settings will be necessary. This also includes a consideration of models for ore genesis, structural features of the proposed site, and the general geologic setting of the site. The identification, ranking, and comparison of ore-forming systems in comparison to the site specific observational data base will be important in assessing undiscovered deposits.

The data that remain to be collected (described above) will be important in contrasting different areas of the site and in comparisons to conceptual ore-deposit types. This information will be used, in part, in assessing the potential for undiscovered deposits in the area of the site and should help provide a basis on which to fully assess the mineral or other resource potential of the proposed site.

Expert Panel or Peer Review Reports: As site characterization continues, expert panels or peer reviews are likely to play an important role in reviewing the results of the data collected. They may recommend that new studies be initiated, that studies be continued as planned. In addition, because there will continue to be a diversity of opinion, about the occurrence of and potential for natural resources in the Great Basin, expert panels or peer reviews are likely to be needed to fully evaluate the regulatory guidelines.

Dissemination of Information: Postclosure performance of the site with regard to natural resources will be based in part on the perception of resource potential by the resource industries. Consequently, it is important for the public to be well informed about this aspect of the Yucca Mountain area. Public awareness can be accomplished by disseminating the findings of site studies through technical and nontechnical publications that have wide circulation.

Documentation Needed to Finalize Issue 2: It is recommended that priority be placed on documenting the direct and indirect human interference activities that could potentially affect the waste isolation capabilities of the site. This report should contain (1) information on the kinds of activities, including non-traditional exploration or mining activities, that could occur; (2) in qualitative terms, a ranking of the effects of such activities, including the probability of such activities affecting the waste isolation capabilities of the site; and, (3) definitions, assumptions, and direction to any future work to assess the effects of direct or indirect human interferences. Peer review of this report by a qualified team of experts may be valuable for enhancing its credibility.

2.3.9 HUMAN INTERFERENCE TECHNICAL GUIDELINE: POSTCLOSURE SITE OWNERSHIP AND CONTROL

2.3.9.1 Statement of Qualifying Condition

Qualifying Condition [10 CFR 960.4-2-8-2(a)]: "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 § 960.4-1."

2.3.9.2 Discussion

This guideline is one of the two guidelines included in the Human Interference Technical Guideline. These guidelines focus on (1) reducing the incentive for postclosure human interference by avoiding sites where natural resources are present and (2) obtaining land ownership in order to establish appropriate passive controls and thus decrease the likelihood of incompatible human activities. Note that the Environmental Protection Agency has indicated [40 CFR 191.14(a)] that active institutional controls should not be assumed to be effective for more than 100 years after closure.

The requirements of 10 CFR Part 60 discussed in the qualifying condition include "(1) Both the geologic repository operations area and the controlled area shall be located in and on lands that are either acquired lands under the jurisdiction and control of DOE, or lands permanently withdrawn and reserved for its use; and (2) These lands shall be held free and clear of all encumbrances, if significant, such as: (i) rights arising under the general mining laws; (ii) easements for right-of-way; and (iii) all other rights arising under lease, rights of entry, deed, patent, mortgage, appropriation, prescription, or otherwise."

2.3.9.3 Status of Current Information for Postclosure Site Ownership and Control

Summary of Environmental Assessment Findings for Postclosure Site Ownership and Control

The Environmental Assessment (EA) evaluation considered the favorable and potentially adverse condition associated with this guideline. Table 2-12 summarizes the EA findings (DOE, 1986) for this guideline. The favorable condition is "Present ownership and control of land and all surface and subsurface mineral and water rights by the DOE." This condition is not present for the Yucca Mountain site because the DOE does not own all the land. The potentially adverse condition is "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." This condition was determined not to be present because all land that is required by the qualifying condition is under

Table 2-12. Summary of Environmental Assessment Findings for Postclosure Site Ownership and Control (DOE, 1986)

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

federal ownership, and transfer of rights to the DOE appears feasible. This qualifying condition is linked to the Postclosure System Guideline (Section 2.4), because ownership and control is assumed to help ensure continued functioning of the repository far into the future without adverse human interference.

No impediments were found in the EA evaluation to eventual complete ownership and control of the necessary land by the DOE. Consequently, the evidence did not support a finding that the site was not likely to meet the qualifying condition for Postclosure Site Ownership and Control (Level 3).

Review of Information Obtained since the Environmental Assessment for Postclosure Site Ownership and Control

Since publication of the EA, five events have occurred that are relevant to the evaluation of this guideline and support the conclusion reached in the EA evaluation:

1. The Military Lands Withdrawal Act of 1986 (MLWA, 1986). This Act withdrew the Nellis Air Force Base Range for a period of 15 years. Authority was given to the Secretary of the Interior, through the U.S. Bureau of Land Management (BLM), to issue rights-of-way on the Range, with the concurrence of the Air Force. Surface management of the Range was assigned to the U.S. Department of Interior (DOI).

2. Right-of-Way Reservation (ROWR) N-47748 (BLM, 1988). This ROWR, granted January 6, 1988, gave the DOE' authority to conduct site characterization on the public land administered by the BLM in the proximity of Yucca Mountain. The ROWR did not deny entrance or use by others, but did require consultation by the BLM with the DOE on later applications by others for use in the area.

3. Mining Claims. Thirty-one mining claims were staked and encumbered part of the public land administered by the BLM. These claims did not, to the knowledge of the DOE, produce a "discovery" of minerals and, therefore, are thought to have been nuisance claims. Because the claims have been abandoned, the encumbrance has been removed.

4. Right-of-Way Reservation N-48602 (BLM, 1989) This ROWR, granted October 10, 1989, gave the DOE authority to conduct site characterization on the Nellis Air Force Base Range in the proximity of Yucca Mountain. Because this area is withdrawn, other uses, including mining claims, are restricted.

5. 43 CFR Public Land Order (PLO) 6802 (1990). This PLO, published September 25, 1990, in the Federal Register, withdrew a critical part of the public land around Yucca Mountain from the operation of the mining and mineral leasing laws.

2.3.9.4 Conclusions and Recommendations for Further Activities for Postclosure Site Ownership and Control

The DOE has been successful thus far in its land interactions for the site characterization phase of the program. The site is located on three parcels of federal land, and a process exists for acquiring those lands for the potential repository (Congressional withdrawal). If the site is deemed suitable in all other technical aspects, it seems just a matter of process in pursuing the appropriate avenues for withdrawing the land. Only unforeseen political circumstances, which do not appear more likely at Yucca Mountain than any other site, would stop such an action. Therefore, on the basis of past successful land interactions, an identified process for land withdrawal, and the appropriate expertise for pursuing such a process, the consensus of the Core Team is that current information supports a finding that the site meets the qualifying condition for Postclosure Site Ownership and Control and that new information is unlikely to change this conclusion (Level 4). The pursuit of land permits, processes, and other consultations is assumed to continue as needed to accomplish required goals.

2.4 EVALUATION OF THE POSTCLOSURE SYSTEM GUIDELINE

2.4.1 Summary of Findings in the Environmental Assessment for the Postclosure System Guideline

The Environmental Assessment (DOE, 1986) presented preliminary evaluations of the Postclosure Technical Guidelines that supported the conclusion that the Yucca Mountain site is suitable for site characterization. The evaluation showed that hydrologic, geologic, and geochemical conditions at the site were likely to be compatible with waste isolation and containment. Preliminary performance assessments conducted for both the total system and the engineered barrier system (EBS) indicated that the associated regulatory criteria were likely to be met.

The performance analyses did not quantitatively evaluate the potential for adverse effects on repository performance by disruptive processes or events such as faulting or human intrusion. But, assessments of the favorable and potentially adverse conditions for the technical guidelines that address these processes "uncovered no information that indicates that the Yucca Mountain site is unsuitable for further characterization or that it is likely to be disqualified...after site characterization and more refined analyses of system performance" (DOE, 1986).

Performance analyses for the System Guideline indicated that the expected 10,000-year release of radionuclides was likely to be less than the release limits specified in the Environmental Protection Agency (EPA) standards. Expected releases for 100,000 years were not expected to exceed EPA's 10,000-year release limits. The analysis, however, identified many sources of uncertainty, including paucity of data and incomplete understanding of certain natural phenomena, such as ground-water flow in fractures, the tectonic regime, and the impact of oxidizing conditions in the unsaturated zone.

The EA also evaluated whether conditions at the site would allow the EBS to meet regulatory criteria. Considering only uniform corrosion of the container, the expected lifetime of the waste package was shown to exceed 3,000 years; therefore, the waste-package-lifetime criterion of 300 to 1,000 years would be met. As a consequence of waste-package lifetime, the criteria for protection of individuals and ground-water would be satisfied since those criteria apply only for the first 1,000 years. The EA recognized uncertainties in waste-package performance because information was not available to evaluate more complex degradation modes. Nevertheless, specific information at that time indicated that the waste-package lifetime requirement would not be met.

The EA analysis used a simple, congruent-leaching model to represent the release from the EBS. This simple model showed that the fractional rate of release from the EBS would be less than 2.5 x 10^{-9} per year. Even accounting for time dependence of the radionuclide inventories, this result implies that the EBS release-rate criterion would be met assuming the simple model is an adequate representation. Again, the EA recognized that important uncertainties existed, but no specific information was identified that indicates that the EBS release-rate requirement would not be met.

In summary, the EA analyses concluded that although the degree of uncertainty remained high with regard to certain site features and conditions, the favorable geohydrologic conditions expected for the site gave substantial confidence that the waste would be isolated and contained for the prescribed period. Consequently, a lower-level suitability finding was made for the Postclosure System Guideline.

2.4.2 Review of Information Obtained since the Environmental Assessment for the Postclosure System Guideline

No comprehensive performance assessment that evaluates the suitability of the Yucca Mountain site has been conducted since the EA. A variety of performance studies have, however, been conducted for other purposes, such as to identify data needs and guide testing, to develop performance assessment capabilities, and to support development of program strategies. Some information from these studies is useful in evaluating site suitability. In addition, some limited sensitivity studies were performed specifically to support this early site suitability evaluation. These sensitivity studies used simple models consistent with the level of information that presently is available for the site.

The remainder of this section discusses the studies that are relevant to the site suitability evaluation. These studies are presented in chronological order, and no order of importance is intended. The discussions summarize the conclusions of these studies and identify major uncertainties and issues of concern raised by these studies. Table 2-13 lists the studies, along with the performance measures and reference for each.

Bounding Analysis of Expected Performance

An early study by Sinnock et al. (1984) provides relevant information regarding projected cumulative releases of radionuclides. This study involved deterministic calculations of releases using a simple one-dimensional transport code. Some additional analyses were also conducted using one-dimensional "legs" to estimate the importance of two-dimensional effects, such as the lateral diversion of water. The study emphasized cases generally associated with anticipated conditions, but also considered several cases for extreme conditions, such as ground-water flux up to 20 mm per year, high solubility of uranium oxide with high-flux contacting the waste, and no retardation effects. Gaseous radionuclide releases were not evaluated.

The calculated radionuclide releases via ground-water pathways were more than seven orders of magnitude below the EPA release limits for the assumed conditions. Under the assumptions used, the source term alone, except for short-lived radionuclides, would be less than the EPA release limits. The key factor in determining the releases was the low net rate of infiltration of ground water into the site unsaturated zone that would be available to dissolve radionuclides and transport them to the water table. Releases approaching the EPA release limits could be obtained by combinations of conditions which, though not precluded by site information, were considered unlikely by the authors.

Table 2-13. Studies Completed since the Environmental Assessment Applicable to the Early Site Suitability Evaluation

Study	Performance Measures	Reference
Bounding analysis of expected performance	Cumulative release	Sinnock et al. (1984)
Site Characterization Plan (SCP)		
Section 8.3.5.13	Cumulative release	DOE (1988a)
Section 8.3.5.14	Individual protection	
Section 8.3.5.15	Ground-water protection	
Section 8.3.5.9	Waste-package containment period	
Section 8.3.5.10	EBS release rate	
SCP Section 8.4	Cumulative release	DOE (1988a)
Exploratory Shaft Facility (ESF) Design Acceptability Analysis	Cumulative release	DOE (1989a)
Spent-fuel study	Cumulative release EBS release rate	Apted et al. (1989)
Disruptive performance	Cumulative release	Sinnock (1989)
Container degradation	Waste-package containment period	Farmer and McCright (1989)
Performance Assessment Calculational Exercise	Cumulative release EBS release rate	Barnard and Dockery (1991a) Apted et al. (1991)
Nuclear Regulatory Commission (NRC) Phase I Analysis	Cumulative release	Nuclear Regulatory Commission (1990)
Alternative licensing strategies study	Cumulative release	Golder Associates (1990)
Electric Power Research Institute Risk Analysis	Cumulative release	McGuire et al. (1990)
Calico Hills Risk-Benefit Analysis	Cumulative release	DOE (1991b)

Table 2-13. Studies Completed since the Environmental Assessment Applicable to the Early Site Suitability Evaluation (continued)

Study	Performance Measures	Reference
Exploratory Shaft Facility Alternatives Study	Cumulative release	Stevens and Costin, Editors (1991)
Carbon-14 studies	Carbon-14 release	Van Konynenburg (1991)
Test prioritization	Cumulative release	Mattson et al. (1991)
Release from fracture flow	Cumulative release	Gauthier et al. (1991)
Gaseous release analyses	Cumulative release	Ross et al. (1991)
Performance assessment scoping studies for site suitability	Cumulative release	Shuman et al. (1991) McGuire and Shaw (1991)

Although many uncertainties were recognized, their specific impact on the results was explored through parametric calculations, rather than being included explicitly in the probability of meeting regulatory criteria. Major uncertainties that were acknowledged include those associated with the geohydrology of the unsaturated zone, such as those due to fast paths and to details of the competition between matrix flow and fracture flow; with geochemistry, in particular, the uncertainty in geochemical retardation; and with the treatment of the source term. The report noted that these uncertainties could affect whether applicable regulatory standards would be met.

Site Characterization Plan

The Site Characterization Plan (SCP) (DOE, 1988a) describes DOE's strategy to characterize the Yucca Mountain site, including plans to obtain data to resolve postclosure performance issues and to assess postclosure performance. Cumulative release requirements are addressed in SCP Section 8.3.5.13 (Total System Performance). The individual and ground-water protection requirements are addressed in SCP Sections 8.3.5.14 and 8.3.5.15, respectively. Waste-package containment period is addressed in SCP Section 8.3.5.9, and EBS release rates are addressed in SCP Section 8.3.5.10. The features and conditions of the site considered important to resolution of postclosure performance issues and to evaluating postclosure performance are identified in extensive performance allocation tables in these sections.

Features and conditions important to postclosure performance were identified based on reviews of site information available at the time the SCP was written and from previous postclosure performance assessments. Section 8.3.5.13, which discusses the cumulative release performance measure, provides estimates based on simple models for two disruptive-scenario classes, namely human-intrusion drilling and igneous intrusion. The estimates for the drilling scenarios produced expected releases on the order of 1 percent of the EPA release limits. Estimates for the igneous intrusion scenario were closer to the EPA limits, but did not exceed them. Extremely conservative assumptions were used in each of these analyses. In neither case was the probability of occurrence of the scenarios taken into account when estimating the probability of exceeding the release limits.

SCP Section 8.4 and Exploratory Shaft Facility Design Acceptability Analysis

Analyses were conducted in support of Section 8.4 of the SCP (DOE, 1988a) and in the Exploratory Shaft Facility Design Acceptability Analysis (DOE, 1989a) to evaluate the potential effects of test facility construction and site characterization on future repository performance. These analyses considered the potential effect of construction on the hydraulic properties of the host rock and the extent of the disturbed zone around excavated openings. The effect of water that might be used in construction was evaluated. The analyses included assessments of effects on cumulative release, and the results are consistent with those reported in the EA. The analyses showed that these disturbances would not significantly affect site characteristics important to the postclosure performance measures.

Spent-fuel Study

Apted et al. (1989) assessed system performance as part of an evaluation of the performance of spent fuel as a waste form. The study used a sophisticated model to evaluate waste-package performance, but used a fairly simple method to estimate system releases rather than an integrated system model. Nevertheless, the expected aqueous releases were consistent with those from other studies, such as Sinnock et al. (1984) who used a somewhat more sophisticated model of flow and transport at the site than did Apted et al. (1989). Gaseous releases were evaluated and estimated to be less than 1 percent of the EPA release limit for carbon-14, although uncertainties in the source term for carbon-14 gaseous release were recognized. The key factors affecting performance and the major uncertainties identified in this study included those recognized by Sinnock et al. (1984).

Estimates of Disruptive Performance

For a presentation to the NRC Advisory Committee on Nuclear Waste, Sinnock (1989) considered a wide range of potentially disruptive conditions. These were based in part on earlier work reported in Sinnock et al. (1984, 1987) and in part on judgments made by Sinnock at that time. He estimated probabilities and consequences and attempted to account for uncertainties in these estimates. Within the context of the uncertainties and the models considered, it was difficult to find conditions under which the EPA release limits would be violated. Sinnock noted that carbon-14 gaseous releases are the most likely types of releases to exceed the EPA release limits.

Not all effects were completely bounded in the analyses. The major sources of uncertainty recognized in the study included uncertainties in conceptual models and in the representation of flow and transport at the Yucca Mountain site.

Container Degradation-Mode Survey

Since the EA, potential degradation modes for waste containers have been evaluated. Such studies have been conducted to help select waste-package materials and designs and to evaluate waste-package performance. A survey by Farmer and McCright (1989) reviewed the current understanding of container corrosion, and some of this work was reported in the Performance Assessment Calculational Exercises (PACE) Working Group 2 analyses (Apted et al., 1991) discussed the next section. Iron- and nickel-based austenitic alloys, such as stainless steels and Inconel, and copper-based alloys are the leading candidates for container materials. The types of degradation that have the greatest uncertainty and that are receiving the greatest attention are localized corrosion (pitting) and stress-corrosion cracking. Although it is generally believed that the waste-package containment period will meet the regulatory criteria, definitive results are not yet available, and it is not yet possible to predict the expected length of waste-package containment periods with high confidence.

Performance Assessment Calculational Exercises

The PACE (Barnard and Dockery, 1991a; Apted et al., 1991) were conducted in 1989 and 1990 to identify gaps in performance assessment analytic capabilities. Three working groups were convened. Working Group 1 addressed cumulative release. Working Group 2 focused on waste package and EBS performance measures and the source term for the cumulative release analyses. Working Group 3 reviewed the conceptual models for flow in the unsaturated zone and the approaches to evaluation of ground-water travel time. Results from Working Groups 1 and 2 are discussed here. The Working Group 3 results, however, are not related to the performance measures of the system guideline and are not discussed here. Ground-water travel time is considered in the evaluation of the Postclosure Geohydrology Technical Guideline, which is discussed in Section 2.3.1 of this ESSE report.

Working Group 1 evaluated the ability to calculate cumulative release by applying a variety of tools to several well-defined problems. For example, the problem of aqueous releases was evaluated using SUMO (Eslinger, 1991); TRACRN, a version of the TRACR3D code (Travis, 1984); TOSPAC (Dudley et al., 1988); a combination of DCM-3D (Updegraff et al., 1991) and NEFTRAN (Longsine et al., 1987); and a combination of LLUVIA (Hopkins and Eaton, 1990), NORIA (Bixler, 1985), and FEMTRAN (Martinez, 1985). Gaseous releases were evaluated using simple analytic techniques, as well as the multiphase TOUGH code (Pruess, 1987).

Although no effort was made to represent the Yucca Mountain site completely, the cases chosen did use relevant Yucca Mountain site information to the extent possible. The analyses showed that for the conditions assumed, no significant aqueous transport to the water table would occur in 100,000 years. Indeed, the calculations predicted concentrations less than 1×10^{-10} curies per cubic meter within 100 meters of the water table in 10,000 years.

For gaseous carbon-14, expected releases were on the order of 15 percent or less of the EPA release limit, but with a probability of 10 percent or higher that some releases may exceed the EPA limit. This is a significant probability because the regulation requires that the probability of exceeding the release limits not exceed 10 percent.

Important uncertainties identified in these analyses include those associated with the geohydrology: fracture/matrix interactions, lateral heterogeneity, vapor phase effects, boundary conditions, effects of interfaces between units, and three-dimensional, heterogeneous flow. Other uncertainties are associated with the treatment of retardation, and with the treatment of the source term, particularly the consistency between assumptions for flow and transport. Although the magnitudes of these uncertainties were not estimated, they were considered potentially significant, perhaps large enough to increase the estimates of cumulative release by several orders of magnitude.

The role that some of the uncertainties might play in assessments of performance measures was evaluated through specially designed sensitivity studies. Both parameter and conceptual-model uncertainties were evaluated. For example, Gallegos et al. (1991) evaluated the probability distributions associated with alternative conceptual models of the flow system.

Working Group 2 evaluated the ability to predict EBS release rates by focusing on a few selected scenarios that were chosen to establish bounds on the conditions that might affect EBS release. These include scenarios in which water fills the waste packages, moisture-bearing rubble contacts the waste packages, and a scenario in which no liquid water contacts the waste packages. Process models more sophisticated than the congruent dissolution model used in the EA were developed to address the solubilities of individual elements, alteration of the spent-fuel matrix, release from the spent-fuel cladding and from gaps within the fuel rods, gaseous release, and diffusion and advection processes in the vicinity of the spent fuel.

These process models were incorporated into integrated performance assessment models and applied to the analyses of the EBS. The analyses showed that where the releases are controlled by the solubility of the elements, the release rates from the EBS are likely to be well below the regulatory limits (e.g., for actinides and tin). Where liquid water is present and elemental solubilities are high, as for iodine, cesium, and technetium, releases would be controlled by the alteration of spent fuel and could be greater than the limit specified in the regulations. Current information indicates that the alteration rates could be high because of the oxidizing conditions in the unsaturated zone. Also, volatile radionuclides residing in the gaps in the spent-fuel rods could be released quickly when the waste packages and the rods are breached, if the waste packages are emplaced in unsaturated rock. The predicted release rates could be significantly reduced by taking into account the wetting and breaching of the waste packages and averaging the release rates for individual packages over the entire array of breached and unbreached waste packages. However, the models for breaching of the waste package were not sufficiently well developed to determine what the revised release rate would be.

U.S. Nuclear Regulatory Commission Phase I Analysis

Early in 1990, the NRC conducted a feasibility study to examine important performance assessment issues associated with the Yucca Mountain site (NRC, 1990). A new system model was developed that used a probabilistic "shell" connecting component models for processes. The component models relied on the results of analyses of relatively complex computer codes. For example, the SUTRA code (Voss, 1984) was used for flow in the unsaturated zone, and the NEFTRAN code (Longsine et al., 1987) was used for transport.

The NRC emphasized that the analyses were not intended as an analysis of the Yucca Mountain site. Nevertheless, the parameters and models used are representative of this particular site. The NRC attempted to use assumptions and models appropriate for the Yucca Mountain site and the results for expected performance were consistent with those reported in the EA and in the other studies cited here.

The study also examined unanticipated processes and events, in particular, extreme infiltration and human interference. The analyses indicated that a combination of these two conditions in concert with certain assumptions and parameters, such as a significant probability of low retardation for plutonium, could result in releases exceeding the EPA limits. Factors potentially important to system performance identified in this study include depth to the water table, potential of the rock units to sustain fracture flow, infiltration flux, fraction of infiltrating ground water contacting the waste, uranium matrix solubility, and the saturated hydraulic conductivity for the Calico Hills vitric unit. Other important factors identified include the potential for gaseous release of carbon-14, non-vertical flow effects, and transport characteristics of plutonium that include colloid formation, retrograde solubility, and sensitivity of chemistry to oxidation state.

Major uncertainties identified by this study were the conceptual and physiochemical models, as well as the models and data for predicting scenarios for predicting waste package failure, and for representing flow and transport in partially saturated, fractured rock. The study indicated that these uncertainties could be significant and that definitive conclusions regarding system performance could not be made without additional site information to reduce these uncertainties substantially.

Alternative Licensing Strategies Study

Golder Associates (1990) estimated the impact of increased site information utilized in conceptual models and model parameters on performance assessments. A simple probabilistic system model was developed to represent processes and uncertainties regarding those processes. Using that model, it was found that disruptive processes that cause direct release to the accessible environment provide the only conditions under which the EPA standards might not be met. The report noted that the analyses contain a number of important sources of uncertainty, including boundary conditions, geohydrology of the unsaturated zone and saturated zone, transport in fault zones, matrix diffusion in the saturated zone, gaseous-release source term and retardation, and probabilities for disruptive processes and events. These associated uncertainties were considered to be significant.

Electric Power Research Institute System Analysis

A project under the sponsorship of EPRI (McGuire et al., 1990) demonstrated that an event-tree approach that had successfully been applied to the evaluation of seismic hazards at reactor sites (Jack R. Benjamin and Associates, Inc. et al., 1988a,b) could also be used for performance assessment of the repository system. This demonstration involved the explicit treatment of 11 distinct conditions and features (e.g., geohydrology, waste-form performance, tectonics, and volcanism). Cumulative releases were calculated for selected radionuclides using a simple probabilistic system model developed for the study. This model explicitly incorporated discrete probabilities for some of the uncertain variables.

The representation for the geohydrology of the unsaturated zone was essentially the same as was used in the studies described above. Predicted performance was also consistent with the results of those studies. Using parameters consistent with current understanding and practice for the treatment of climatic change, tectonics, and volcanism, the study predicted compliance with EPA release limits. Major uncertainties in this study included treatment of the geohydrology of the unsaturated zone and the effects of disruptive processes and events not considered in the analysis. The report did not, however, determine the particular significance of the impacts of these uncertainties on predicted releases. However, it was recognized that they could be important and should be addressed before definitive findings could be made.

Calico Hills Characterization Risk/Benefit Analysis

DOE (1991d) evaluated the potential impacts of testing in the Calico Hills unit, which directly underlies the potential repository host-rock unit. Impacts included the risks as well as the benefits of information to be obtained from testing in this unit. Various strategies for characterizing the Calico Hills unit were developed and evaluated. The assessments of performance were judgments by experts, who relied on results of earlier studies, as well as on limited scoping analyses. Cumulative-release estimates for various modes of ground-water transport through this unit, taking into account the effects of characterization as well as the information to be obtained from testing, were used to compare the strategies. The estimates of cumulative release were well below the EPA release limits in all strategies, and differences among various strategies were small (1 to 10 percent). These results reflect a judgment that there is little likelihood of impacts of testing on performance and little likelihood that the information obtained by testing in the Calico Hills unit would change the conclusions about whether release limits can be met. Note, however, that the DOE has been encouraged to investigate the Calico Hills unit and its ability to attenuate and retard transient moisture pulses as early as possible (Freeze et al. in DOE, 1991d).

Exploratory Studies Facility Alternative Configurations Study

Stevens and Costin (eds.) (1991) evaluated alternative configurations for the Exploratory Studies Facility (ESF) that will be used to provide in situ data at depth at the Yucca Mountain site. The potential effects on performance of construction of the ESF within the repository block was one of the factors used to evaluate the alternatives. This study indicated that the important factor affecting repository performance relevant to ESF development was the presence of water at the repository horizon. Consequently, the most important influences on repository performance were (1) introduction of water to the repository horizon and removal of water because of construction, (2) aspects of the design (e.g., the ESF layout and means of access), and (3) sealing techniques that might be used. Estimates of cumulative release were elicited from experts whose judgments were based largely on previous studies that had been performed.

Carbon-14 Studies

Van Konynenburg (1991) reviewed available information on the potential for release of carbon-14 in gaseous form and concluded that the gas could be transported rapidly through the unsaturated zone. He also examined potential releases to the accessible environment and the effects on public health and safety. He concluded that, although there was a potential for releases exceeding the EPA limits for carbon-14, the effect on public health and safety would not be significant, especially in comparison to natural sources of carbon-14 in the atmosphere.

Test Prioritization Task

The Test Prioritization Task (Mattson et al., 1991) evaluated the proposed testing program to identify those site-characterization activities that might be most useful in identifying features or conditions that would be indicators of site unsuitability. The study focused on tests related to postclosure performance issues, and the measure of importance of a particular condition or feature was the potential effect on cumulative release. A base-line case representative of currently expected conditions was established, and cumulative releases expected for this case were estimated by a panel of experts familiar with postclosure performance assessments for the site. Incremental changes in releases due to particular unsuitable features or conditions were then estimated.

The elicited value for expected cumulative release associated with aqueous transport of radionuclides was about six orders of magnitude below the EPA release limits, consistent with the results of the EA analyses. Potential incremental releases varied widely, depending upon the particular feature or condition considered. Most releases, however, were considered negligible relative to the EPA release limits. A few cases were identified as having some potential for incremental releases approaching a significant fraction of these limits. In particular, releases of gaseous carbon-14 were considered important, as were complexities in geological conditions that could cause performance models to underestimate releases.

The study then estimated the reliability of testing and the relative benefits and costs of new information that could help resolve performance-related uncertainties. The study concluded that there is value in testing related to gaseous release and complex site geology. Other testing, such as that to improve knowledge of the geohydrology and geochemistry was found less valuable with regard to estimates of cumulative releases. The study also cautioned against conducting tests with high probability of false alarm when trying to detect unlikely site conditions.

Release due to Fracture-Controlled Flow

Gauthier et al. (1991) evaluated the consequences of fracture-controlled ("weep") flow using simplified models to estimate aqueous cumulative release. They assumed a simple representation for release from the EBS and for the transport aspects of the release calculations. Within the context of these simplifying assumptions, they determined that releases exceeding the EPA release limits are not likely. Aspects of this analysis are discussed in Section 2.3.1 of this ESSE report.

Gaseous Release Analysis

Ross et al. (1991) evaluated the travel time of gases released from the EBS through the rock in the unsaturated zone at Yucca Mountain. The methods developed for this analysis can also help in understanding gas convection as a mechanism for removal of heat from the repository and the flow of water vapor out of the mountain. The ability to model water vapor transport is important to understanding the overall water balance of the unsaturated host rock, which could be important for the evaluation of aqueous releases as well as carbon-14 transport in the gas phase.

Analyses of carbon-14 gas-phase release predicted transport times from several hundred to tens of thousands of years. Even with very low gas permeabilities and other favorable conditions, the analyses indicated there is a significant probability of travel times less than 10,000 years. Therefore, it would be possible that the predicted 10,000-year cumulative release could exceed the EPA release limits if sufficient carbon-14 is released from the EBS in the gas phase.

Although the range of uncertainty in the travel time is large, it appears that the probability of carbon-14 releases that exceed the EPA limits is significant. These analyses reinforce independent studies by PACE Working Group 2 (Apted et al., 1991) and by Van Konynenburg (1991) that indicate there is a significant probability, perhaps greater than 10 percent, of exceeding the limits for cumulative release of carbon-14. Furthermore, this study indicated that the major uncertainties appear to be those in the source term, i.e., the amount and rate of carbon-14 release in the gas phase, from the waste package, rather than those related to site characteristics.

Performance Assessment Scoping Studies for Early Site Suitability Evaluations

Scoping sensitivity studies were conducted by Shuman et al. (1991) and McGuire and Shaw (1991) to support the DOE's early site suitability evaluation. Quantitative analyses were used to evaluate the effect of specific types of uncertainties on cumulative release. Relatively simple models were used that explicitly incorporate only a few dozen parameters in a given evaluation. In spite of this simplicity, the studies were able to draw a number of conclusions regarding the importance of some of the uncertainties.

The studies investigated both aqueous and gaseous releases. The first conclusion regarding aqueous releases is that the projected cumulative release was less than the EPA release limits. The studies also indicated that releases of anionic species approaching the standard could result from fast pathways (e.g., those with transit times less than 10,000 years) or from large source terms (e.g., fractional waste package release rates exceeding 10^{-4} per year). Given the ranges of uncertainty in site parameters, the studies concluded that current information does not preclude these conditions. The studies also found that a combination of fast paths and small retardation factors for key elements, such as plutonium or americium, could lead to releases approaching the EPA limits. The studies did not, however, estimate the probabilities of such conditions.

These results suggest that three conditions need particular attention in the site characterization program as it addresses the Postclosure System Guideline:

1. Flow mechanisms in the unsaturated zone, particularly the potential for fast paths due to fracture networks and fault zones or at the interfaces of features that have widely different hydrologic properties

2. Retardation mechanisms, particularly for high-inventory radionuclides, such as plutonium and americium

3. The source term, in particular the rate of release from the EBS and the transfer of radionuclides from the EBS to the unsaturated-zone flow system.

The studies did not explicitly evaluate the importance of transport in the saturated zone beneath the water table. Clearly, however, there could be significant effects if the ground-water travel time in the saturated zone is short (e.g., significantly less than 1,000 years).

These analyses also calculated gaseous releases of carbon-14 and found expected cumulative releases to be about 70 percent of the EPA release limits. Individual dose was also calculated, and peak annual whole-body doses on the order of 10 microrems were obtained. The authors noted that this result suggests that the release limit specified for carbon-14 gaseous release may not be consistent with other standards for protection of public health, such as the Clean Air Act, which has an effective dose limit for carbon-14 of 10 millirems per year. Sensitivity studies suggested that the critical factors do not appear to be uncertainties in site conditions, but rather the amount of carbon-14 that could be released from the waste packages in the form of carbon dioxide.

2.4.3 Current Status of Information for the Postclosure Guidelines

This section summarizes current information for the Postclosure Guidelines. It is organized following the major steps depicted in Figure 1-2: disqualifying conditions, performance assessments, and qualifying conditions.

2.4.3.1 Current Status of Postclosure Guideline Disqualifying Conditions

Evaluations of the disqualifying conditions for the Postclosure Technical Guidelines indicate that lower-level (Level 1) suitability findings can be supported in each case; that is, in no instance is it likely that a disqualifying condition is present. Except for the Postclosure Geohydrology Guideline, higher-level suitability findings (Level 2) could also be supported. For this guideline, there are still key unresolved issues regarding the presence of flow paths in which ground-water travel time fails to meet the 1,000-year criterion and the ability to sustain flow in these paths. Factors that need to be evaluated to resolve these issues include (1) the presence of through-going, potentially water-bearing fractures, (2) the interactions between flow in these fractures and in the rock matrix, and (3) the potential for pulses of infiltrating surface water to penetrate deep into the subsurface geohydrologic flow system. Therefore, the Core Team concluded that a higher-level suitability finding for this disqualifying condition cannot presently be supported.

2.4.3.2 Status of the Performance Assessments for the Yucca Mountain Site

The following paragraphs summarize conclusions from analyses of postclosure performance. Results are given for each of the postclosure performance measures in Table 2-13.

Cumulative Radionuclide Releases. The analyses of aqueous cumulative releases conducted since the EA (Section 2.4.2) are generally consistent with the results of analyses conducted for the EA (Section 2.4.1). Expected releases are less than the EPA release limits. The discussion in the Postclosure Geohydrology Guideline evaluation indicates that there are still substantial issues associated with pathways and flow processes that relate directly to the performance of the site (See Section 2.3.1). There is some uncertainty about how the flow system might change as a result of future climatic changes or tectonic processes. In addition, there are significant issues associated with the source term for release calculations (See Section 2.4.2). There may also be issues with retardation factors for plutonium, particularly with regard to sorption on minerals along fast flow pathways or if colloidal transport is viable at this site (See Section 2.3.2).

A possibly important factor that has not yet been evaluated thoroughly concerns the transport of radionuclides in the saturated zone below the water table. Although conservative analyses in the EA did not indicate a strong effect, evidence is accumulating that transport of radionuclides may be slow in this zone and may provide an important contribution to waste isolation at the site. It will be important to evaluate the magnitude of this contribution in future assessments.

Detailed quantitative analyses of the potential effects of disruptive processes and events have not yet been conducted. The technical guideline evaluations indicate at least two categories of scenarios that need to be investigated: tectonic processes and human intrusion.

The first category of scenarios entails disruption of the system that would be induced by tectonic processes (See Section 2.3.7). The evaluation of the postclosure tectonics guideline concluded that there are several important issues relevant to postclosure performance. One issue is the potential effect of tectonic activity on the engineered barrier system. The performance assessments that have been conducted to date show little difference between analyses involving 1,000-year lifetime waste packages and shorter-lived waste packages. Therefore, it is not likely that tectonic disruptions of the waste package would be very important unless such disruptions also involve other phenomena affecting performance, or there is greater reliance on long-lived (e.g., 10,000-year) waste packages.

A second issue associated with tectonic processes is a potential effect on the ground-water flow system such as an increase in the elevation of the water table or a local concentration of flux due to creation of new fast pathways. The performance assessments that have evaluated these effects have indicated that adverse effects would be unlikely. For example, calculations with a hypothetical permanent water table rise of 20 m show virtually no effect on cumulative releases. Likewise, analyses of flux concentration effects show as much likelihood of decreased releases as increased releases because of decreased flow in one part of the repository compensating for increased flux in another part (to maintain the overall water balance). Therefore, the overall effect is not likely to be significant.

A third tectonic-processes issue is the question of volcanism. In this instance, the probability of volcanism at the site is considered very low. Although such effects are not expected, additional information is needed to determine possible impacts on waste isolation and containment.

The second category of scenarios involves human intrusion, primarily associated with drilling through the repository while exploring for potentially valuable resources (See Section 2.3.8). The concern here is transfer of radionuclides to the surface in the drilling fluids and direct release to the environment. The effects would be limited if there is little likelihood of valuable resources in the area or if the probability of drilling on Yucca Mountain is small for other reasons. Current information is not yet sufficient to conclude that this probability is negligible at the present time.

The assessments of gaseous releases conducted by the Test Prioritization Task (Mattson et al., 1991), Van Konynenburg (1991), Ross et al. (1991), and Shuman et al. (1991) indicate that the travel time of carbon-14 from the repository to the surface is expected to be less than 10,000 years. The expected cumulative release of carbon-14 is calculated to range between 1 percent and 70 percent of the EPA release limits in these analyses, depending upon the magnitude of the source term that is assumed. In addition, the uncertainties in the source term are sufficiently large that there is a significant probability that the release limits could be exceeded. This probability is currently calculated by Shuman et al. (1991) to be less than 10 percent. These conclusions could possibly change however, with additional information and are strongly influenced by the performance of the EBS. Analyses to date have assumed that all of the available carbon-14 is released within the 10,000-year performance period. A long-lived waste package would change this assumption. Also, the release limits for carbon-14 could possibly be revised by EPA so that the limits are more in line with the public health and safety consequences established in other EPA standards (e.g., those that implement the Clean Air Act). Therefore, the Core Team feels that a lower-level suitability finding can be supported with respect to cumulative radionuclide releases.

Individual and Ground-water Protection. Few, if any, calculations have been made of individual dose or radionuclide concentrations in special sources of ground water. Likewise, results have not been compared with the individual and ground-water protection requirements of the EPA standard. Nevertheless, the evidence strongly suggests that these requirements would be met, because (1) these requirements apply only to the first 1,000 years after closure, (2) they consider only anticipated processes and events, and (3) the analyses of cumulative release indicate that any releases in this period under anticipated processes and events would be negligible. In addition, it is unlikely that the tuffaceous aquifer below the repository will qualify as a special source of ground water to which the ground-water protection requirement applies.

An important consideration with regard to ground-water protection is the possibility that some contamination of the ground water may occur because of releases from other facilities offsite. If so, the evaluations may need to take into account the combined effects of both repository and off-site releases.

Waste-Package Containment Period. Because the final design and materials for the waste container have not yet been selected, performance assessments for comparison with the waste-package containment period requirement have not yet been conducted. Analyses that take waste-package containment period into account as part of the source term for the cumulative release calculations generally assume some lifetime or distribution of lifetimes that meets this requirement. Such analyses have not considered the effect of a long-lived waste package on the source term and cumulative releases.

The site conditions that would affect waste-package containment period are similar to those at many other locations in which unsaturated conditions prevail. While expected oxidizing conditions at Yucca Mountain set it apart from sites with reducing conditions, these conditions do not suggest that waste packages cannot be designed to meet the waste-package containment period criterion.

Engineered Barrier System Release Rate. Analyses of EBS release rates, based on current design concepts and site information, indicate that the aqueous release rates for most radionuclides are expected to meet the EBS release-rate performance objective. These rates depend on container lifetime, elemental solubilities of the radionuclides, resistance to transport within the waste package, and constraints to diffusion away from the waste package. Current information regarding these factors does not preclude releases of certain radionuclides that exceed the EBS release rate limit. Instead, information suggests that the rate of release of relatively soluble radionuclides could well exceed one part in 100,000 per year if the potentially high waste-form alteration rate for the spent-fuel matrix dominates the release (Lee et al., 1991) and if enough water is available at the site to contact emplaced waste and dissolve the radionuclides.

Analyses for gaseous releases from the EBS, based on current design concepts, indicate that the rate of release of volatile elements could exceed one part in 100,000 per year upon breach of the containers. In most cases, the fraction of these elements that is released rapidly is not significant. A possible exception is carbon-14 as carbon dioxide gas, which may exceed the

EPA release limits. The key uncertainties in this case are those that affect the waste-package containment period discussed above.

2.4.3.3 Current Status of Postclosure Guideline Qualifying Conditions

Technical Guidelines

It is the consensus of the Core Team that lower-level (Level 3) suitability findings can be supported for each of the qualifying conditions for the Postclosure Technical Guidelines. For Dissolution and Erosion Guidelines, higher-level suitability findings can be supported.

For the other technical guidelines, significant issues were identified with regard to particular features or conditions that would need to be resolved before higher-level (Level 4) suitability findings can be supported.

For the Geohydrology Guideline, the key issue is the potential for paths for rapid flow of ground water from the repository to the water table. Present information does not preclude significant release of radionuclides via such paths, if present.

The key issue associated with the Geochemistry Guideline is the possibility of low retardation of certain radionuclides, such as plutonium and americium, along paths of rapid flow. This concern is related to the potential for these anionic species to travel as colloids. Again, the likelihood for such low values of retardation is small, but there is insufficient information about sorption on minerals along these paths to preclude the occurrence of significant releases.

The key issues for the Rock Characteristics Guideline are related to the impacts of heat and radiation produced by the emplaced waste on the flow and geochemical characteristics. Possible areas of concern include effects on the moisture conditions and flow paths in the vicinity of the waste, the effects of heat and/or radiation on sorption through changes to the pH, and effects on the dissolution and alteration rate of the spent fuel under repository conditions.

The key issue associated with the Climatic Change Guideline is the possibility that future climate changes could bring about change in the flow system that could increase the likelihood of paths for rapid flow of ground water. Although the current estimates of future change do not indicate significant effects, evaluation of the potential local increase in rainfall and development of a model that relates infiltration to this increased precipitation need to be evaluated to resolve the issue.

The key issue for the Postclosure Tectonics Guideline is the likelihood of tectonic activity that could degrade the waste-isolation performance of the EBS or the site. Although such effects are not expected, additional site information is needed before the possibility of significant impacts on the performance of the repository system can be precluded.

The key issue for the Human Interference Guideline is the possibility of natural resources at the site. Current information does not indicate that such resources have sufficient promise at this site to provide an incentive for exploration that could lead to intrusion of the repository. However, geochemical studies to evaluate the mineral resource potential of the site could indicate that the potential is higher than presently believed.

System Guideline

The evaluation of the system guideline indicates that aqueous releases are expected to meet the EPA release limits by a significant margin. At this time a higher-level suitability finding cannot be supported, however, because there is insufficient understanding of the conditions of ground-water flow, the magnitude and time-dependence of the source term, the retardation of key radionuclides, the probabilities of faulting, and the probability of occurrence of economic natural resources that could provide an incentive for human intrusion.

The situation for gaseous release is somewhat different. Current information summarized in Section 2.4.2 indicates that expected gaseous releases of carbon-14 are less than the EPA release limits, although additional information could change this conclusion. Current evidence also suggests that the probability of meeting the EPA release limits for carbon-14 does not depend strongly on uncertainties in site information. Rather, the major source of uncertainty appears to be the gaseous carbon-14 source term. Consequently, it is possible that system performance results might not change by obtaining additional site information alone. Instead, it appears that what is needed is a better definition of the source term that should be used to estimate releases of gaseous carbon-14.

With regard to the performance measures for individual and ground-water protection, the lower-level suitability finding still appears to be supported. Furthermore, it is likely that a higher-level finding can be supported for both of these as long as the 1,000-year performance period is still applicable. That is, a very strong case can be made for the low probability of aqueous releases over 1,000 years on the basis of current information. Furthermore, it is likely that the individual protection requirement can be demonstrated for gaseous releases as well as aqueous releases over this period.

For the waste-package-containment performance measure the Core Team concluded that a lower-level suitability finding can be supported. Although materials have not yet been chosen, there appear to be no exceptional site conditions that would prevent a waste package from performing as designed. The principal difficulties in demonstrating compliance in this case are the determination of corrosion modes of container materials and understanding material performance over extended periods. These difficulties are largely independent of characteristics of the Yucca Mountain site, and it does not appear that there are any site characteristics that would prevent the development of waste packages that could successfully meet the regulatory criteria.

For the EBS release-rate performance measure, the results summarized in Section 2.4.2 indicate that, for current EBS design concepts, release rates exceeding the regulatory criterion may occur for several radionuclides. These results depend upon the extremely conservative models used to describe

EBS performance. Two important concerns here include the potential for rapid release of volatile elements upon breach of the container and the potentially high release rate for soluble radionuclides.

The concern for volatile elements is with radionuclides that can be released as gases (e.g., carbon, krypton, and iodine). It will be difficult to demonstrate that the release-rate criterion would not be exceeded by these gases over a short period after breaching. Usually, however, such releases will not cause a problem. For example, iodine is unlikely to yield significant releases because of its high reactivity with components of the system (Lee et al., 1991). Likewise, krypton-85 is short-lived and can probably be ignored because significant cumulative release to the accessible environment is unlikely; that is, the NRC may allow a higher EBS release rate if it can be shown that cumulative release of krypton-85 to the accessible environment is well below the the EPA release limits. Neither of these considerations applies to carbon-14, however, and it may be difficult to discount a rapid release rate if it cannot be shown that the EPA standard for release to the accessible environment can be met.

Rapid aqueous release of soluble radionuclides from the EBS appears to pose a problem because current evidence suggests a potential for rapid alteration of the UO_2 ceramic matrix to cause a large effect on release rate. However, this issue may not be very important, because the relatively soluble radionuclides, iodine and cesium, are not likely to lead to large aqueous releases to the accessible environment.

The Core Team concluded that current information supports a lower-level suitability finding for the Postclosure System Guideline. There are significant issues with regard to gaseous-phase carbon-14 releases to the accessible environment. Future site information could possibly indicate that the EPA standards would not be met for the repository and waste package designs that are presently contemplated. The most important factor in this instance appears to be the regulatory limit that has been specified for carbon-14. The EPA has recognized that this limit represents a negligible public health and safety risk and may not be consistent with the public health and safety risks established in other standards (Clark and Galpin, 1991; Van Konynenburg, 1991). Thus, the release limits for carbon-14 may change, or it is possible that additional information about the source term could change the conclusion that the system guideline is met. Therefore, the Core Team feels that a lower-level suitability finding can be supported for the Postclosure System Guideline.

2.4.4 Steps Needed to Support Higher-level Suitability Findings for the Postclosure System Guideline

Additional Information that Should be Obtained

The summary of findings in Section 2.4.3 suggests that information to support higher-level findings is needed in two categories: (1) cumulative release and EBS release rate of gaseous carbon-14, and (2) aqueous releases. For gaseous releases, information is needed to estimate the carbon-14 gaseous source term. This information includes data on the inventory of carbon-14 susceptible to gaseous release, design information on engineering approaches to mitigate gaseous release, and information on the performance of containers under breached conditions that could result in gaseous releases of carbon-14. If additional information in these areas decreases the probability of meeting the release criterion, some site characteristics may become more important. For example, the travel time of gas from the repository to the surface depends upon the relevant thermal and gas-flow permeability characteristics. If performance is marginal, detailed information on these characteristics may become more important.

The DOE may wish to continue interactions with the EPA on the development of revised standards, including those for gaseous release of carbon-14. The EPA has stated that the regulatory limit for carbon-14 was established without fully considering the risks associated with the gaseous release pathway (Clark and Galpin, 1991). The EPA has also noted that the current issue associated with gaseous carbon-14 release appears to apply to all sites in which waste disposal would be in the unsaturated zone, rather than to particular characteristics of the Yucca Mountain site.

Although lower-level suitability findings can be supported with respect to aqueous releases, current uncertainties are important and need to be addressed in the testing program. The testing program described in the SCP also describes the performance issues discussed here. In particular, the performance allocation tables in the sections of the SCP that specifically address the five postclosure performance measures defined in Table 2-1 in Section 2.2 also identify the site features, conditions, and characteristics considered to be most critical to the resolution of those issues.

The information needed to resolve key uncertainties affecting cumulative release includes the following:

- Ground-water flow pathways, especially identification of fast flow pathways
- Flow processes in the unsaturated zone, especially for fast pathways and details of radionuclide transport, for example, matrix diffusion and dispersion
- Retardation coefficients, especially for radionuclides that may travel as colloids
- Source term, including understanding of the wetting and breaching of containers, and transport of radionuclides from the waste form to the boundaries of the EBS
- Natural resource potential at the site
- Potential for changes to the unsaturated zone flow system, especially the potential for development of fast flow pathways under changed climatic conditions
- Potential for tectonic processes that could affect the EBS or could affect flow pathways.

The information needed to address key uncertainties in the performance of the EBS includes the following:

- Container failure and canister penetrations including the quantity and quality of ground water that would contact the container, and expected rock-induced load on waste packages
- Element-specific data to predict effective diffusion coefficients for transport of radionuclides in liquids in unsaturated tuff and rubble
- Models that take into account resistance to flow and mass transport from failed containers that are mostly intact, from fuel cladding, and from corrosion products
- Models that account for the availability of oxygen and other oxidizing species to predict UO_2 alteration rates and solubilities
- Changes in chemical conditions such as pH, dissolved carbonates, and ionic strength that may be caused by distillation and localized condensation
- Effects of possible colloid formation and colloid-solute interactions on radionuclide release rates
- Studies of evaporation and condensation as affected by repository heat generation and transfer, and studies of the local chemical environment as affected by heat and water-vapor transport.

In addition, more information is needed to support a higher-level suitability finding with regard to the Geohydrology Disqualifying Condition. This information includes the following:

- Presence of pathways of likely and significant radionuclide travel
- Ability of the site to attenuate rapid percolation events and to distribute flow
- Conceptual models of the interactions of matrix and fracture flow in the unsaturated zone
- Effect of gas flow on the distribution of moisture in the unsaturated zone
- Hydraulic properties and hydrologic influence of fault zones at the site.

<u>Ability of Future Testing to Resolve Issues</u>

As indicated throughout Section 2 and, in particular, in the paragraphs above, certain issues need to be resolved before higher-level findings can be supported on all aspects of the Postclosure Guidelines. In most instances, the resolution of issues will involve acquiring additional site information, which may involve testing, analysis, or both. The SCP identifies planned studies that directly address many of these key issues. A list of these studies is given in Table 2-14. Studies in this table are correlated with key information needs identified above.

Current information seems definitive enough to support higher-level suitability findings with respect to the individual protection and ground-water protection requirements. This is because there appear to be no significant uncertainties in the associated performance measures as defined in the current regulation. Consequently, no studies are listed in Table 2-14 for these performance measures.

The current SCP studies do not directly address the following issues:

- Details of processes for wetting and breaching of waste containers

- Mass transfer of radionuclides within waste packages

- Availability of oxygen in the near field and its impact on engineered barriers

- Effect of evaporation, distillation, and conduction in the vicinity of the waste packages.

In some instances, the information needed is not site-specific and would not necessarily be reflected in a study plan, but would be part of design-related activities. The studies and activities in current plans may need to be reviewed and their scope modified to ensure that the needed information is obtained. The uncertainties that give rise to the above information needs are most important if the performance of the system is found to be marginal in terms of uncertainties that remain in understanding flow and transport in the host rock. If additional site information increases confidence about favorable flow and transport conditions at the Yucca Mountain site, more detailed understanding of near-field and design-specific information needs may not be important and those information needs may not need to be satisfied.

Table 2-14. Site Characterization Studies Planned to Address Key Postclosure Performance Uncertainties

Performance Measure	SCP Study	Topic
Cumulative release		
Pathways	8.3.1.4.2.1	Stratigraphic units at the site
	8.3.1.4.2.2	Structural features at the site
	8.3.1.4.2.3	Three-dimensional geologic model
	8.3.1.4.3.2	Three-dimensional model of rock characteristics at the site
	8.3.1.2.2.9	Site unsaturated zone (UZ) modeling and synthesis
Flow processes	8.3.1.2.2.3	UZ percolation (Surface-based tests)
	8.3.1.2.2.4	UZ percolation (Exploratory Studies Facility tests)
	8.3.1.2.2.8	Fluid flow in unsaturated fractured rock
Retardation	8.3.1.3.4.1	Batch sorption studies
	8.3.1.3.4.3	Sorption models
	8.3.1.3.5.2	Colloid behavior
	8.3.1.3.6.1	Dynamic transport column experiments
	8.3.1.3.7.1	Applicability of lab data to repository transport
Source term	8.3.1.3.6.2	Radionuclide diffusion
Natural resources	8.3.1.9.2.1	Natural resources at Yucca Mountain
	8.3.1.9.2.2	Water resources at Yucca Mountain
Changes to flow system	8.3.1.5.1.6	Future regional climate and environments
	8.3.1.5.2.2	Future regional hydrology due to climate changes
	8.3.1.8.3.1	Effects of tectonic processes and events on average percolation flux rates
	8.3.1.8.3.2	Effects of tectonic processes and events on changes in water-table elevation
	8.3.1.8.3.3	Effects of tectonic processes and events on local fracture permeability and effective porosity
Individual protection	None	
Ground-water protection	None	

Table 2-14. Site Characterization Studies Planned to Address Key Postclosure Performance Uncertainties (continued)

Performance Measure	SCP Study	Topic
Waste-package Containment Period	8.3.4.2.4.1	Near-field chemistry
	8.3.4.2.4.2	Near-field hydrology
	8.3.4.2.4.3	Near-field mechanical properties
Engineered Barrier System Release Rate		
Container performance	8.3.4.2.4.1	Near-field chemistry
	8.3.4.2.4.2	Near-field hydrology
	8.3.4.2.4.3	Near-field mechanical properties
Diffusion coefficients	8.3.1.3.6.2	Radionuclide diffusion
Near-field chemistry	8.3.4.2.4.1	Near-field chemistry
Ground-water Travel Time		
Infiltration	8.3.1.2.2.1	UZ infiltration
	8.3.1.2.2.2	Water movement tracer tests using chlorine-36
	8.3.1.2.2.3	UZ percolation (Surface-based tests)
	8.3.1.2.2.4	UZ percolation (ESF tests)
	8.3.1.2.2.5	Moisture diffusion tests in ESF
Fracture-matrix interactions	8.3.1.2.2.8	Fluid flow in unsaturated, fractured rock
Gas movement impacts	8.3.1.2.2.6	Gas movement in UZ
Hydraulic properties of fault zones	8.3.1.4.2.2	Structural features within site
Conceptual models of preferential paths	8.3.1.2.2.7	Hydrochemistry of UZ
	8.3.1.2.2.8	Fluid flow in unsaturated, fractured rock
	8.3.1.2.2.9	Site UZ modeling and synthesis
	8.3.1.4.2.1	Stratigraphic units at the site
	8.3.1.4.2.2	Structural features at the site
	8.3.1.4.2.3	Three-dimensional geologic model
	8.3.1.4.3.2	Three-dimensional model of rock characteristics at the site

Report of Early Site Suitability Evaluation of the Potential Repository Site at Yucca Mountain, Nevada

SECTION 3: EVALUATION OF PRECLOSURE GUIDELINES

January 1992

3.0 EVALUATION OF THE PRECLOSURE GUIDELINES

3.1 DESCRIPTION OF THE PRECLOSURE GUIDELINES

The Preclosure Guidelines describe the siting considerations associated with the repository system before it is closed, for example, during construction or emplacement of wastes. The implementation guidelines (10 CFR 960.3-1-6) direct that these considerations be given secondary significance relative to the postclosure guidelines in the site evaluations. The Preclosure Guidelines address the following groups of considerations: (1) Preclosure Radiological Safety; (2) the Environmental, Socioeconomic, and Transportation-related impacts associated with repository development; and (3) the Ease and Cost of Repository Siting, Construction, Operation, and Closure. The groups are listed in order of decreasing importance, as directed by the implementation guidelines.

The Preclosure Guidelines provide system and technical guidelines in each of these three groups. The System Guideline in each group establishes the overall objective of the guidelines to be met by a repository system during the preclosure period. The Technical Guidelines establish the specific issues to be considered in the evaluation. These guideline groups and their intended purposes are discussed in more detail in Sections 3.1.1 through 3.1.3.

3.1.1 Radiological Safety Guidelines

The objective of the Preclosure Radiological Safety Guidelines is defined in the qualifying condition for the system guideline for that group [10 CFR Part 960.5-1(a)(1)]:

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

The pertinent features and conditions in this case are the site characteristics that (1) affect radionuclide transport through the surroundings; (2) could affect the performance of engineered components that function to control releases of radioactive materials; and (3) relate to the location and distribution of people in unrestricted areas who might be affected by radionuclide releases. According to 10 CFR 960.3-1-6, this guideline group is assigned the greatest importance among the preclosure guidelines because it is directed at protecting both the public and repository workers from radiological exposures. The Technical Guidelines in this group include (1) Population Density and Distribution; (2) Site Ownership and Control; (3) Meteorology; and (4) Offsite Installations and Operations. Evaluations of these guidelines are presented in Section 3.3.1.

3.1.2 Environmental Quality, Socioeconomic Impacts, and Transportation Guidelines

The Preclosure Guidelines ranked next in importance are the guidelines that address the environmental, socioeconomic, and transportation-related impacts of the repository. The objective of these guidelines is stated in the system guideline for this group [10 CFR Part 960.5-1(a)(2)]:

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

The pertinent features and conditions for evaluating these guidelines are (1) those related to lifestyles, sources of income, social and esthetic values, and community services; (2) the air, land, water, plants, animals, and cultural resources in the areas potentially affected by repository activities; (3) characteristics of the transportation system and infrastructure; and (4) information regarding potential mitigation measures that might be used to achieve compliance with the requirements of the System Guideline. The technical guidelines in this group include (1) Environmental Quality; (2) Socioeconomic Impacts; and (3) Transportation. Evaluations of these guidelines are presented in Section 3.3.2.

3.1.3 Preclosure Ease and Cost of Repository Siting, Construction, Operation, and Closure Guidelines

These guidelines do not relate directly to the health, safety, or welfare of the public or the quality of the environment, and consequently are ranked lower in importance than the postclosure guidelines (10 CFR Part 960.3-1-6). These guidelines relate to (1) the site features and conditions that affect the ability to test, construct, operate, or conduct other activities at the site; (2) the engineering, materials, and services necessary to conduct these activities; and (3) occupational health and safety of repository personnel.

The broad requirements that apply to the preclosure ease and cost considerations are stated in the system guideline for this group of guidelines [10 CFR Part 960.5-1(a)(3)]:

> "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."

These requirements are not imposed by bodies outside the DOE and will not be the subject of the licensing process. DOE has imposed them on itself to ensure that the plans for siting (including site characterization), construction, operation, and closure are reasonable and take into account availability of the technology needed for these activities. The technical guidelines in this group identify the detailed geologic considerations that are important to meet the requirements of the system guideline. These considerations include (1) Surface Characteristics (e.g., topography and terrain); (2) Rock Characteristics (e.g., those related to the maintenance of openings or safety of workers); (3) Hydrology (e.g., potential for flooding or effects of the hydrology on construction); and (4) Tectonics (e.g., seismic and volcanic hazards for surface facilities). Evaluations of these guidelines are presented in Section 3.3.3.

3.2 NATURE OF THE EVALUATIONS OF THE SITE AGAINST THE PRECLOSURE GUIDELINES

The approach to the evaluation of siting guidelines that is described in Section 1.3 has three elements: (1) evaluation of the site to determine if any of the disqualifying conditions specified in the technical guidelines are present; (2) system assessments; and (3) evaluation of the site to determine if any of the qualifying conditions of the guidelines cannot be met. This approach applies to each of the preclosure guideline groups differently because the focus of the groups differ.

A similar approach is applicable to the evaluation of the preclosure guidelines. In this instance, the system assessments must be those that are appropriate for the objectives of each of the preclosure guideline groups. The system assessments for preclosure radiological safety must include assessments of the repository system design with respect to its ability to protect the public and workers from radioactivity in the preclosure period. Similarly, the system assessments must address the potential environmental, socioeconomic, and transportation-related impacts associated with the development and operation of the repository and the measures available to mitigate unacceptable impacts such as avoiding the impacts altogether, minimizing impacts, rectifying impacts, and compensating for the impacts. The system assessments to address the ease and cost guidelines must evaluate the requirements the site features and conditions place on technology and on the availability of this technology.

3.3 EVALUATION OF THE PRECLOSURE TECHNICAL AND SYSTEM GUIDELINES

The following sections first present the evaluations of the Technical Guidelines for each group of guidelines, followed by an evaluation of the System Guideline. Sections 3.3.1.1 through 3.3.1.4 present the evaluations of the Technical Guidelines for Preclosure Radiological Safety; Section 3.3.1.5 presents the System Guideline evaluation for Preclosure Radiological Safety. Similarly, the Technical Guideline evaluations for Environmental Quality, Socioeconomic Impacts, and Transportation are presented in Sections 3.3.2.1 through 3.3.2.3, and Section 3.3.2.4 presents the System Guideline evaluation for this group of guidelines. Finally, Sections 3.3.3.1 through 3.3.3.4 present the evaluations of the Technical Guidelines for Ease and Cost of Siting, Construction, Operation, and Closure; Section 3.3.3.5 presents the System Guideline evaluations for this group of guidelines.

3.3.1 EVALUATION OF GUIDELINES FOR PRECLOSURE RADIOLOGICAL SAFETY

The focus of the evaluation of the Preclosure Radiological Safety Guidelines is to determine if surface and underground repository facilities can be designed to meet applicable regulatory limits for radiological exposures. These limits are identified in 10 CFR Part 20, 10 CFR Part 60, and 40 CFR 191, Subpart A.

There is already considerable practical experience in the design of nuclear facilities, such as nuclear power plants and spent-fuel handling facilities, to meet such limits. Much of the technology to be applied to the repository was developed for service in reprocessing facilities where particulate and gaseous releases are controlled. By nature, the repository environment should be less challenging to effluent control systems than facilities that reprocess spent fuel. Such experience indicates that, as long as factors such as site meteorology and local population distribution are not outside the design basis, there should be high confidence that these requirements can be met.

The approach to this evaluation, therefore, is to examine the Yucca Mountain site to determine if conditions or features are present that are sufficiently extreme that there might be uncertainty about the ability to ensure the repository facilities can be designed to meet radiological safety requirements. The consensus of the Core Team is that conclusions about the suitability of the site do not require that the design of facilities or analyses of the projected exposures during the preclosure time period be complete. Instead, based on experience with design and radiological safety assessments of similar facilities, this evaluation focuses on particular features and conditions that may make such activities difficult or uncertain.

As indicated in Section 3.1.1, the pertinent features and conditions for evaluation preclosure radiological safety are (1) site characteristics that affect radionuclide transport through the surroundings; (2) those that could affect performance of engineered components that function to control releases of radioactive materials; and (3) those that determine the location and distribution of people in unrestricted areas who might be affected by radionuclide releases. These features and conditions are addressed in the technical guidelines in this section: Population Density and Distribution (Section 3.3.1.1); Site Ownership and Control (Section 3.3.1.2); Meteorology (Section 3.3.1.3); and Offsite Installations and Operations (Section 3.3.1.4). Section 3.3.1.5 then reviews the results of the Technical Guideline evaluations to determine the status of information supporting the System Guideline qualifying condition.

3.3.1.1 POPULATION DENSITY AND DISTRIBUTION TECHNICAL GUIDELINE

3.3.1.1.1 Statement and Discussion of Qualifying and Disqualifying Conditions

<u>Qualifying Condition [10 CFR 960.5-2-1(a)]</u>: "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)."

<u>Disqualifying Condition [10 CFR 960.5-2-1(d)]</u>: "A site shall be disqualified if--(1) any surface facility of a repository would be located in a highly populated area; or (2) any surface facility of a repository would be located adjacent to an area 1 mile by 1 mile having a population of not less than 1,000 individuals as enumerated by the most recent U.S. census; or (3) the DOE could not develop an emergency preparedness program which meets the requirements specified in DOE Order 5500.3 (Reactor and Non-Reactor Facility Emergency Planning, Preparedness, and Response Program for Department of Energy Operations) and related guides or, when issued by the NRC, in 10 CFR Part 60, Subpart I, Emergency Planning Criteria."

<u>Discussion</u>. Both criteria established above for the qualifying condition for this guideline depend on the preclosure radiological safety requirements in 10 CFR Part 20, 10 CFR Part 60, and 40 CFR Part 191. In addition, the first criterion is predicated on the definition of "highly populated area," which is stated in 10 CFR 960.2 to be "any incorporated place of 2,500 or more persons, or any census designated place 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 are specifically excluded from the definition of "place" in 10 CFR 960.2.

Two of the disqualifying conditions are also predicated on demographic characteristics and radiological safety requirements. The second disqualifying condition requires that the surface facilities not 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." The discussion of the development of the second disqualifying condition suggests that the intent was to avoid placing the surface facilities either in an urban area or abutting an urban area. Therefore, evaluating the population characteristics of the area surrounding Yucca Mountain, particularly in relation to the location of the repository surface facilities, will address the qualifying condition and the first two disqualifying conditions.

The third disqualifying condition requires that DOE comply with its own requirements for emergency preparedness planning, as specified in DOE Order 5500.3A (DOE, 1991h).

3.3.1.1.2 Approach for Population Density and Distribution Evaluation

Evaluation of the qualifying condition and the first two disqualifying conditions is dependent upon the ability to design the repository system, including surface facilities, to protect the public from exposure to radiation and to meet the requirements established by the Preclosure Radiological Safety System Guideline (10 CFR 960.5-1(a)(1)). Population characteristics of the area surrounding Yucca Mountain (as enumerated by each decennial census) are part of the basis for evaluating this guideline. In addition, if or when the requirements of 40 CFR Part 191 are revised, the qualifying and disqualifying conditions of this guideline should be reviewed.

Under the third disqualifying condition, the site would be disqualified if an emergency preparedness plan that met the requirements of either DOE Order 5500.3A (DOE, 1991h) or 10 CFR 60, Subpart I, could not be prepared. A determination of the likelihood of this occurrence must be made. The regulations for developing emergency planning criteria, for which 10 CFR 60, Subpart I, has been reserved, do not presently exist. Therefore, the evaluation of the third disqualifying condition is limited to evaluating the requirements of DOE Order 5500.3A (DOE, 1991h).

3.3.1.1.3 Status of Current Information for Population Density and Distribution

Summary of Environmental Assessment Findings for Population Density and Distribution

The information presented in the Environmental Assessment (EA) supported a Level 3 (lower-level suitability) finding for the qualifying condition and Level 2 (higher-level suitability) findings for the first and second disqualifying conditions (DOE, 1986). The EA, which was based upon information provided by the 1980 census, indicates that the closest "highly populated area" would be the Las Vegas urban area, approximately 85 miles from the location of the surface facilities. Furthermore, the closest 1 mile by 1 mile area having a population of 1,000 or more individuals was also in the Las Vegas urban area, 85 miles from the Yucca Mountain site. The information regarding the qualifying condition presented on pp. 6-20 and 6-21 of the EA resulted in a finding that "Preliminary calculations indicate that even the expected worst-case radiological dose will not exceed the limits of 10 CFR 960.5-1(a)(1) (1984) and will be negligible when compared to the background radiation dose." On the basis of that evaluation, the EA stated that "the evidence does not support a finding that the site is not likely to meet the qualifying condition for population density and distribution," which resulted in a Level 3 finding.

For the third disqualifying condition, the evaluation in the EA states that an emergency preparedness plan and notification procedures for loss of control of radioactive materials leading to a hazard or potential hazard to public health, safety, or property had been prepared for the Nevada Test Site (NTS). A Memorandum of Understanding (MOU) between the State of Nevada and the DOE Nevada Operations Office (DOE/NV) (State of Nevada, 1984) allows DOE/NV to use its personnel or contractors, as well as appropriate state and local agencies, to respond to any NTS-related accidents or incidents that affect locations beyond the NTS boundaries. The MOU also states that the DOE/NV Radiological Assistance Team will respond, upon request by any first-on-the-scene authority, to any off-site radiological accident or incident. On this basis, the EA concluded that the preparation of an emergency plan for the repository would present no problem (DOE, 1986); the EA made no statement as to whether the NTS plan met the requirements of DOE Order 5500.3A (DOE, 1991h). This order applies to DOE site-specific emergency plans for radiological emergencies occurring in either existing or planned DOE reactors and non-reactor facilities.

Review of Population Density and Distribution Information Obtained since the Environmental Assessment

While the complete 1990 census data are not yet available and analyzed, the initial information indicates that the closest "highly populated area" will be the unincorporated town of Pahrump, approximately 40 miles from the Yucca Mountain site, and the closest 1 mile by 1 mile area with a population of 1,000 or more persons will be in the unincorporated town of Beatty approximately 20 miles from the site, or in the unincorporated town of Pahrump. The 1980 and 1990 census data do not provide exact information concerning the closest residents to the site. Information from the radiological monitoring program, however, indicates that the closest resident population is in the Lathrop Wells/Amargosa Valley area, approximately 10 to 14 miles from the Yucca Mountain site, but this population does not meet the population density definitions in the guidelines.

Since the EA was published, administration of the DOE's Yucca Mountain Site Characterization Project (YMP) has changed, and it is no longer administered directly under the DOE/NV. However, DOE/NV is still the "landlord" of the NTS land where the support facilities for the potential repository facility would be located. Under Subtitle H, Section 180(c) of the Nuclear Waste Policy Amendments Act of 1987 (NWPAA, 1987), funding and assistance provisions are made for the training of public safety officials through whose jurisdictions spent nuclear fuel may be shipped. This training is specific to the procedures required for safe, routine transportation of spent nuclear fuel, as well as to procedures for dealing with emergency-response situations. Plans and procedures to be developed would be integrated with overall NTS emergency response plans that are in force at that time. The availability of the funds and assistance is considered a means of promoting state and local government participation in the development of an emergency preparedness program.

As part of a report to the U.S. Congress, the DOE summarized DOE/NV involvement with, and support of, the State of Nevada in the area of emergency-response training for accidents involving radioactive materials (DOE, 1988b). In Annex F (December, 1990) of the draft DOE/NV Management Agreement (DOE, 1990c) the Yucca Mountain Site Characterization Project Office agreed to work with and to take direction from DOE/NV in the development of emergency plans and procedures and to participate in emergency-response planning activities and exercises. Plan preparation and implementation are the responsibility of the Yucca Mountain Site Characterization Project Office, while the establishment of plan requirements and plan approval are the responsibility of DOE/NV.

3.3.1.1.4 Conclusions and Recommendations for Future Population Density and Distribution Activities

Qualifying Condition. There are two reasons the Core Team concluded that a higher-level suitability finding can be supported for the qualifying condition of this guideline. First, because the Yucca Mountain site is not located on or adjacent to a highly populated area, there is nothing to suggest that the site will not meet the requirements of this qualifying condition. Second, there is little likelihood that factors related to population would affect the ability to design facilities that would meet the individual dose limits of the regulations. Therefore, it is the consensus of the Core Team that available information supports a higher-level suitability finding (Level 4) on the qualifying condition.

Disqualifying Conditions. Level 2 (higher-level suitability) findings have already been reached for the first two disqualifying conditions (DOE, 1986). The information provided by the 1990 census will have to be evaluated to assess changes in regional population characteristics and to determine whether areas closer to Yucca Mountain meet the definition of "highly populated area" or have a population of 1,000 or more persons within a 1 mile by 1 mile area. However, it is unlikely that the 1990 census data will affect the Level 2 findings for the first two disqualifying conditions.

The consensus of the Core Team is that a higher-level suitability finding (Level 2) can also be supported for the third disqualifying condition. That is, there is no reason to believe that the DOE would not be able to approve emergency preparedness plans for the repository program in accordance with DOE Order 5500.3A (DOE, 1991h) and there is little likelihood that additional information would indicate otherwise.

Discussion

Since higher-level suitability findings currently are supported for all conditions of this guideline, no future activities to resolve open issues are required. However, additional information on population density and distribution will be obtained. In particular, the DOE will obtain (1) final data from the 1990 census, (2) additional information regarding the location of repository surface facilities, and (3) specific repository design parameters regarding release of radiation.

The Core Team recommends that the Yucca Mountain Site Characterization Project actively support the emergency preparedness program being conducted by DOE/NV to the greatest extent practicable, including participation in the Radiological Assistance Team activities and in radiological response exercises. The team also suggests that DOE monitor the status of 10 CFR 60, Subpart I, and, when appropriate, actively participate in the development of those criteria.

3.3.1.2 PRECLOSURE SITE OWNERSHIP AND CONTROL TECHNICAL GUIDELINE

3.3.1.2.1 Statement and Discussion of the Qualifying Condition

Qualifying Condition [10 CFR 960.5-2-2(a)]: "The site shall be located on land for which the DOE can obtain, in accordance with 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)."

Discussion. The qualifying condition for this guideline is linked to the Preclosure Radiological Safety System Guideline. Land ownership and control is necessary to preclude radiological exposure of the general public and hazardous releases of radioactive materials beyond the boundaries of the repository surface facilities and associated restricted areas. The requirements of 10 CFR 60.121, discussed in the qualifying condition, include the following: "(1) both the geologic repository operations area and the controlled area shall be located in and on lands that are either acquired lands under the jurisdiction and control of DOE, or lands permanently withdrawn and reserved for its use; and (2) these lands shall be held free and clear of all encumbrances, if significant, such as (i) rights arising under the general mining laws; (ii) easements for right-of-way; and (iii) all other rights arising under lease, rights of entry, deed, patent, mortgage, appropriation, prescription, or otherwise."

3.3.1.2.2 Status of Current Information for Preclosure Site Ownership and Control

Summary of Environmental Assessment Findings for Preclosure Site Ownership and Control

The Environmental Assessment (EA) evaluation (DOE, 1986) considered the favorable and potentially adverse conditions associated with this guideline. The favorable condition is "present ownership and control of land and all surface and subsurface mineral and water rights by the DOE." This condition was not found to be present in the EA because the DOE does not own all the land required by the qualifying condition. The potentially adverse condition is "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." This condition was determined not to be present because all the land that is required by the qualifying condition is under Federal ownership, and the transfer of rights to the DOE appears feasible.

No impediments were found in the EA evaluation to the eventual ownership and control of the necessary land by the DOE. Consequently, it was determined that the evidence did not support a finding that the site was not likely to meet the qualifying condition for Preclosure Site Ownership and Control (Level 3).

Review of Preclosure Site Ownership and Control Information Obtained since the Environmental Assessment

Since the EA was published, five events have occurred that are relevant to the evaluation of this guideline:

1. The Military Lands Withdrawal Act of 1986 (MLWA, 1986). This act withdrew the Nellis Air Force Base Range for a period of 15 years. Authority was given to the Secretary of the Interior, through the Bureau of Land Management (BLM), with the concurrence of the Air Force, to issue rights-of-way on the range. Surface management of the range was assigned to the Department of Interior (DOI).

2. Right-of-Way Reservation (ROWR) N-47748 (BLM, 1988). This ROWR, granted January 6, 1988, gave the DOE the authority to conduct site characterization on the public land administered by the BLM in the proximity of Yucca Mountain. The ROWR did not deny entrance or use by others, but it did require consultation by the BLM with the YMPO on later applications by others for use of the area.

3. Mining Claims. Thirty-one mining claims were staked and encumbered part of the public land administered by the BLM. These claims did not, to the knowledge of the DOE, produce a "discovery" of minerals and, therefore, are thought to have been nuisance claims. Because the claims have been abandoned, the encumbrance has been removed.

4. Right-of-Way Reservation N-48602 (BLM, 1989). This ROWR, granted October 10, 1989, gave the DOE authority to conduct site characterization on the Nellis Air Force Base Range in the proximity of Yucca Mountain. Since this area is withdrawn, other uses, including mining claims, are restricted.

5. 43 CFR Public Land Order 6802 (1990). This order, which was published September 25, 1990, in the Federal Register, withdrew a critical part of the public land around Yucca Mountain from the operation of the mining and mineral leasing laws.

3.3.1.2.3 Conclusions and Recommendations for Future Preclosure Site Ownership and Control Activities

Thus far, the DOE has been successful in its land interactions for the site characterization phase of the program. The site is located on three parcels of federal land, and a process exists (Congressional withdrawal) for acquiring those parcels if the site is selected for repository development. If the site is deemed suitable in all other technical aspects, it seems to be only a matter of process to pursue the appropriate avenues for withdrawing the land. Therefore, based upon the assumptions of past successful land interactions, an identified process for land withdrawal, and the appropriate expertise for pursuing such a process, the consensus of the Core Team is that current information supports a higher-level suitability finding for the qualifying condition for the Site Ownership and Control Guideline and that new information is unlikely to change this conclusion (Level 4).

3.3.1.3 METEOROLOGY TECHNICAL GUIDELINE

3.3.1.3.1 Statement and Discussion of the Qualifying Condition

Qualifying Condition [10 CFR 960.5-2-3(a)]: "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)."

Discussion. The qualifying condition ties "expected" meteorological conditions to meeting the System Guideline for allowable exposures of the public to radioactive material. The role of meteorology in meeting the system guideline is in two primary areas:

1. Transport and dispersion of airborne radionuclide material that may be released during repository operation and closure

2. Extreme weather occurrences that could interfere with repository operation to the degree that unacceptable exposures could result, such as from accidents

3.3.1.3.2 Approach for Meteorology Evaluation

It is not likely that radioactive material in excess of the amount allowable under the requirements specified in 10 CFR 960.5-1(a)(1) will ever become airborne so that atmospheric dispersion or preferential transport would become an issue. However, the qualifying condition requires that consideration be given to design features that limit routine releases, such as ventilation systems, and to the potential for weather conditions to cause an accident.

Yucca Mountain is located in a sparsely populated mountainous area. The complex topography plays an important role in determining regional weather, including atmospheric dispersion and extreme weather events. Licensing requirements are likely to necessitate extensive documentation of conditions, but existing information allows for good scientific judgments and some assumptions to be made.

The role of meteorology in meeting the System Guideline depends upon the design of the facilities. For example, the potential release of radionuclides to unrestricted areas depends, in part, on radiological source concentration, which is a function of design factors. Similarly, severe weather events become important only when they exceed the design basis of the repository facilities. The main focus of this guideline analysis, however, is on the site meteorological conditions that play a role in limiting potential releases from the proposed facilities.

3.3.1.3.3 Status of Current Meteorology Information

Summary of Environmental Assessment Findings for Meteorology

Regional climatological conditions were documented in the Environmental Assessment (EA) (DOE, 1986) based on information from the nearby Yucca Flat area on the Nevada Test Site and from monitoring in the town of Beatty. The EA evaluation concluded that occurrences of severe weather are infrequent and would not be expected to significantly affect repository construction, operation, or closure. Deep atmospheric mixing in the region was determined to contribute to the effective dispersion of airborne radionuclides if any were released from the repository. The prevailing wind directions were considered not likely to cause preferential transport of airborne radionuclides toward regional population centers. The finding for this qualifying condition was a Level 3 (lower-level) suitability finding, which means that the evidence does not support a finding that the site is not likely to meet the qualifying condition.

Review of Meteorology Information Obtained since the Environmental Assessment

Since the EA, the meteorological monitoring program has produced regular quarterly summary reports, the latest for December through February 1989 data (SAIC, 1990). Data, however, have been collected from 1985 through 1989 and additional reports are available. These data indicate general climatic conditions similar to expectations based on the historical data from Yucca Flat. There are differences, however, in some parameters (e.g., precipitation) between Yucca Mountain and Yucca Flat (Flint, 1991). Local dispersion conditions are being calculated using data from a network of stations.

Preliminary reviews of the results from the monitoring network indicate occurrences of nighttime drainage winds down Fortymile Canyon toward the Amargosa Valley area and nighttime winds blowing over the ridge of Yucca Mountain in a westerly direction. While these results require further review, they do not represent unsuitability concerns given that the technology exists to design facilities such that releases of radioactive material greater than that allowable under the regulations will be controlled. In addition, prevailing winds at the site are such that overall effective dispersion is apparent. A study plan for the characterization of the meteorology as part of the regional hydrology studies presents additional data and assumptions for the expected meteorological conditions of the Yucca Mountain area (DOE, 1991a).

Additional information strengthens the conclusion that there is no indication that the qualifying condition cannot be met. The following statements can be made regarding meteorological conditions:

1. Atmospheric dispersion. Typical weather in the Yucca Mountain area includes two probable dispersion conditions. One condition is frequent periods of very good atmospheric dispersion, which would not create preferential transport toward populated areas. The other condition is some nighttime periods of limited dispersion that could provide transport toward the Amargosa Valley area. The Amargosa Valley townsite is approximately 14 miles south of the Yucca

Mountain site; this distance is expected to add to effective dispersion characteristics. Also, given the prevailing winds described on a daily, monthly, seasonal, and annual basis, good atmospheric dispersion is apparent (SAIC, 1990). The above information supports the conclusion that dispersion characteristics are not expected to contribute to a potential dose of radioactive material to any population in the Amargosa Valley area in excess of the amount allowable under the regulations, should a release occur.

2. Severe weather. The likelihood of extreme weather occurring that could interfere with repository operations is extremely low. These types of events include hurricanes, tornadoes, severe floods, and severe winter storms.

3.3.1.3.4 Conclusions and Recommendations for Future Meteorology Activities

The prevailing meteorological conditions provide good atmospheric dispersion, thereby reducing the possibility of preferential transport of any released radioactive material, and the likelihood of severe weather conditions impacting repository operations is extremely low (due to infrequency of events and adequate design). Thus, the consensus of the Core Team is that current information supports a higher-level (Level 4) suitability finding for this qualifying condition and that new information is not likely to change this conclusion.

Discussion

Continued meteorological monitoring as part of site characterization and planned environmental programs will provide useful confirmatory information to support this conclusion. In addition, site modeling will better characterize the dispersion characteristics and provide input for the comprehensive dose assessment calculations that will be needed to address the System Guideline for Preclosure Radiological Safety.

3.3.1.4 OFFSITE INSTALLATIONS AND OPERATIONS TECHNICAL GUIDELINE

3.3.1.4.1 Statement and Discussion of the Qualifying and Disqualifying Conditions

Qualifying Condition [10 CFR 960.5-2-4(a)]: "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 requirements specified in §960.5-1(a)(1)."

Disqualifying Condition [10 CFR 960.5-2-4(d)]: "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."

Discussion. Section 960.5-1(a)(1), referenced in the qualifying condition, is the System Guideline for Preclosure Radiological Safety. This guideline specifies 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 safety requirements set forth in 10 CFR Part 20, 10 CFR Part 60, and 40 CFR 191, Subpart A (See appendix II of this part)."

There are several items in the qualifying and disqualifying conditions that need clarification, including terminology and the potential implications of other licensed and unlicensed facilities in the Yucca Mountain region. The Nuclear Waste Policy Act of 1982 (NWPA, 1983) defines "atomic energy defense activity" to be "any activity of the Secretary performed in whole or in part in carrying out any of the following functions:

(A) Naval reactor development;

(B) Weapons activities including defense inertial confinement;

(C) Verification and control technology;

(D) Defense nuclear materials production;

(E) Defense nuclear waste and materials by-products management;

(F) Defense nuclear materials security and safeguards and security investigations; and

(G) Defense research and development."

The Secretary of Energy controls several facilities in Nevada for the purposes of carrying out a primary mission of

> "an on-continent site for the testing of nuclear weapons. In addition, the NTS has been assigned secondary missions that include: (1) disposal of Defense Programs (DP) radioactive low-level waste (LLW) and mixed waste (MW); (2) execution of tests involving large quantities of hazardous gases (e.g. natural gas, hydrogen fluoride); and (3) conducting of specialized tests involving radiation and radioactive materials" (DOE, 1990h).

Nearby facilities other than the Yucca Mountain site include the Nevada Test Site (NTS), the Central Nevada Test Site, Nelson Seismic Station, Mt. Brock Communications Site, and the Project Shoal site. DOE-related activities also occur on the Tonopah Test Range (TTR), which is part of the Nellis Air Force Range land withdrawal (SAIC/DRI, 1991). These facilities are shown on the map of southwestern Nevada in Figure 3-1. Because of the greater separation distance and the lack of current or planned activities that would likely affect repository activities at the CNTS, Nelson Seismic Station, Mt. Brock Communications Site, and the Project Shoal site, the evaluation of this guideline is focused on current and planned activities at the NTS and TTR facilities.

The TTR is operated for the DOE by Sandia National Laboratories. The TTR is used jointly by the 37th Tactical Fighter Wing and the DOE, as well as by other units scheduled by the 554th Range Group at Nellis Air Force Base (SAIC/DRI, 1991).

3.3.1.4.2 Issues Related to the Qualifying Condition for Offsite Installation and Operations

Two issues relative to site selection are defined by this condition. The first is interpreted to require the evaluation of potential effects from all neighbors on the safety of the preclosure phase of a nuclear waste repository. The second is interpreted to require that a summation of radionuclide releases from the site and its neighbors will not exceed applicable radionuclide release limits. A neighbor is defined here to be any facility within the appropriate environmental region (e.g., airshed and ground-water system) such that effects from the repository and the neighboring activity would have a combined impact on offsite receptors.

An issue that is related to off-site facilities is the extent to which ground-water contamination from neighboring activities, when summed with the releases from a repository, will be treated in the postclosure phase (Rogers, 1991). For this evaluation, this issue is considered under the Postclosure System Guideline (Section 2.4).

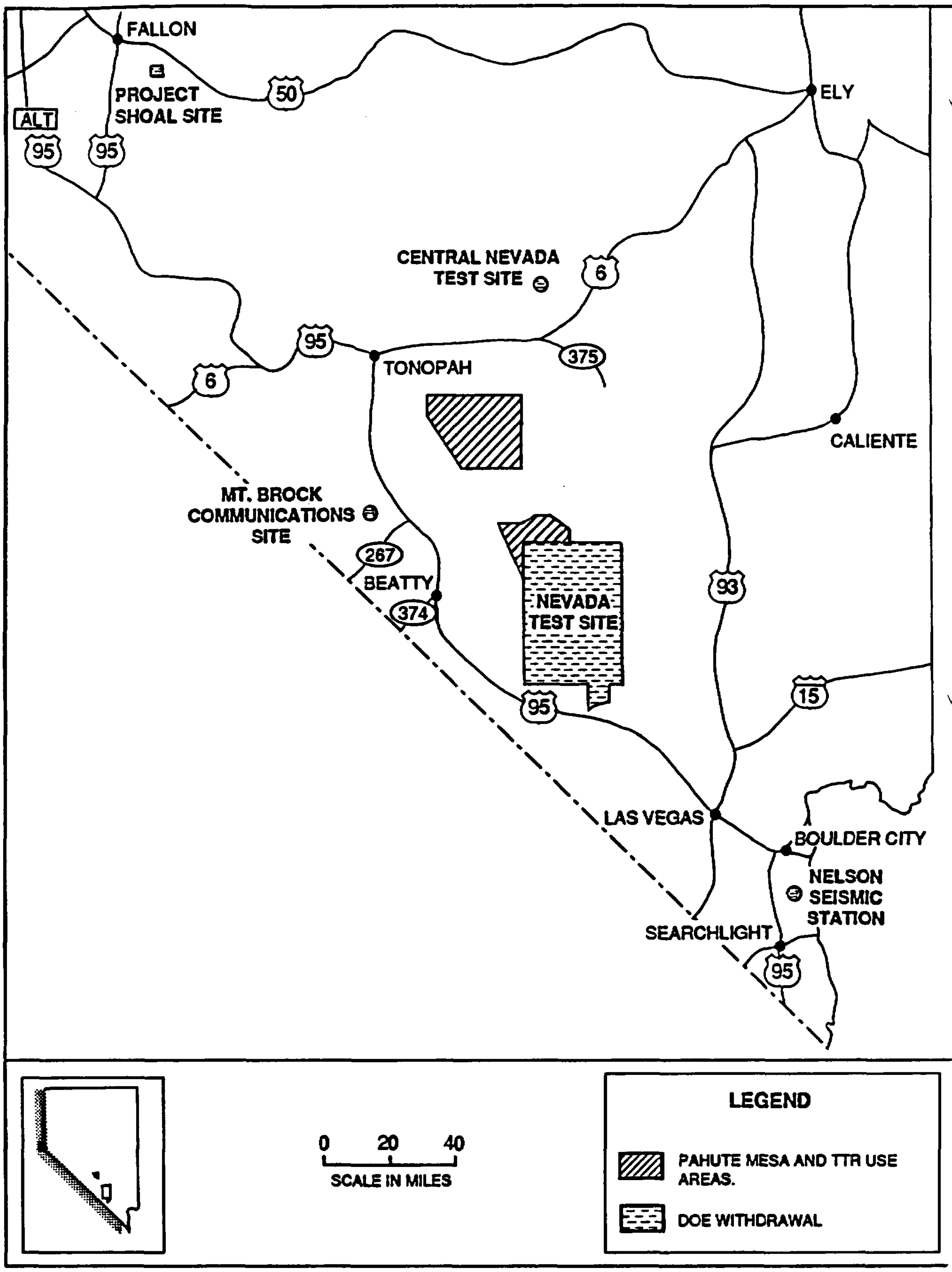


Figure 3-1. Land withdrawals and use areas associated with Department of Energy activities.

Potential effects that could be credible for the preclosure repository period from current and planned neighbors include the following:

1. Ground motion

2. Air quality

3. Water quality

4. Ionizing radiation

5. Non-ionizing radiation

6. Solid and hazardous waste

7. Noise and sonic booms

8. Facility accidents

   - explosions
   - fires
   - releases of significant quantities of hazardous materials
   - releases of significant quantities of radioactive material

9. Aircraft mishaps

10. Objects dropped from aircraft

11. Transportation of hazardous materials.

3.3.1.4.3 Issues Related to the Disqualifying Condition for Offsite Installations and Operations

For this evaluation, activities at the TTR and NTS are assumed to be atomic energy defense activities. Commercial and other defense activities in the neighborhood of Yucca Mountain were not considered in evaluating the disqualifying condition.

A definition of "irreconcilable conflict" is not provided in the Nuclear Waste Policy Act (NWPA, 1983). For purposes of this report, a conflict for the repository was assumed to result if atomic energy defense activities could (a) not be accomplished because of safety implications covered by the qualifying condition, or (b) the presence of atomic energy defense activities would preclude the successful development of a repository for other reasons. Likewise, conflicts could result for atomic energy defense activities if effects (safety or otherwise) from the repository would preclude successful completion of their mission. Irreconcilable is interpreted to mean that, if a conflict is identified, no reasonable engineering, administrative, or other mitigation methods would allow both missions to be accomplished.

For this evaluation, it is assumed that conflict type (a), described in the preceding paragraph is covered under the qualifying condition, and that conflict type (b) either is covered by other guidelines or is nonexistent.

For potential conflicts on atomic energy defense activities, the following effects were considered to represent the range of potential conflict sources:

1. Air quality
2. Water quality
3. Ionizing radiation
4. Non-ionizing radiation
5. Solid and hazardous waste
6. Noise
7. Facility accidents
   - explosions
   - fires
   - releases of significant quantities of hazardous materials
   - releases of significant quantities of radioactive material
8. Transportation of hazardous materials
9. Security
10. Use of scarce resources needed for continued mission support.

3.3.1.4.4 Approach for Offsite Installations and Operations Evaluation

The approach for this guideline evaluation included the following steps:

1. Identify and characterize offsite facilities with the potential to create effects encompassed by the qualifying and disqualifying conditions.
2. Conduct an evaluation of planned and potential offsite facility effects on the repository and effects of the repository on atomic energy defense activities.
3. Identify and evaluate mitigation measures appropriate to both the qualifying and disqualifying conditions, if needed.
4. Compare evaluation results with applicable standards. If potential compliance with standards can be demonstrated on the basis of known site information, available technology or administrative procedures, the higher-level suitability finding can be supported for the qualifying and disqualifying conditions.

3.3.1.4.4.1 Basis for Qualifying Condition Evaluation for Offsite Installations and Operations

Estimates of effects from NTS, the commercial low-level waste burial ground near Beatty, the TTR, mining in the Yucca Mountain area, hazardous material transportation, and the Nellis Range activities are to be cataloged. If it can be shown that these effects are included in the the current conceptual design (SNL, 1987), are negligible based on available site data, or are mitigatable through reasonable and available engineering or administrative means, then the qualifying condition would be supported, and new information is unlikely to change this conclusion.

3.3.1.4.4.2 Basis for Disqualifying Condition Evaluation for Offsite Installations and Operations

Estimates of effects from a potential repository at Yucca Mountain are also to be cataloged. If it can be shown that these effects either are negligible by physical separation or can be mitigated by reasonable and available engineering or administrative means to levels that do not conflict with atomic energy defense activities, then the disqualifying condition would not be present, and new information would be unlikely to change this condition.

3.3.1.4.5 Status of Current Information for Offsite Installations and Operations

3.3.1.4.5.1 Summary of Environmental Assessment Findings for Qualifying Condition for Offsite Installations and Operations

The Environmental Assessment (EA) (DOE, 1986) addressed the NTS, the Nellis Range, and commercial nuclear operations. Effects considered included ground motion from underground nuclear explosions (UNE), radioactive emissions from UNEs, releases from spent fuel then stored in the Nevada Research and Development area (note: this fuel is no longer present), commercial low-level waste disposal facility near Beatty, Nevada, and aircraft crashes from overflights of U.S. Air Force (USAF) aircraft. No significant potential for radioactive releases in excess of standards was identified in the EA. This conclusion was based on predicted doses to the maximally exposed individual of less than 100 mrem for all identified accidents. The worst-case accident identified for off-site activities was an aircraft crash into the waste-handling building, with a frequency of less than 2×10^{-10} per year and a predicted consequence of 68 mrem to the maximally-exposed individual member.

Test areas for UNEs are currently 24 to 33 miles north and east of the Yucca Mountain site. If a repository were constructed at the site, it would be built to withstand ground motion from both UNE and natural sources. The maximum ground motion (99 percent confidence) from UNEs was predicted to be 0.32g. This was an extremely conservative estimate in that it considered the ground motion that would result from UNEs much larger than currently allowed under the Threshold Test Ban Treaty and at a test location much closer to Yucca Mountain. The EA stated that a repository at the Yucca Mountain site could be designed and constructed using available technology to withstand the maximum credible predicted ground motion, whether natural or induced.

Radioactive releases from underground nuclear explosions have caused onsite air samples to contain tritium and xenon-133 slightly above background levels. However, in four out of five years before the EA, no detectable offsite airborne releases were recorded. The dose that a maximum individual would receive from these releases was predicted to be 0.011 mrem per year. This is a small fraction of the background radiation (approximately 69 mrem per year measured at Lathrop Wells) occurring in the area (EPA, 1990) and of the NRC radiation protection standard of 100 mrem per year in 10 CFR Part 20.

The commercial low-level waste disposal facility near Beatty, Nevada, is monitored by the Environmental Protection Agency (EPA). This site is 19 miles west and south from the Yucca Mountain site. Releases from this facility are not covered by the regulations specified in the Preclosure System Guideline and therefore would not be taken into account in assessing impacts of offsite facilities. Even so, no significant releases from the facility are expected.

The USAF currently uses airspace in the vicinity of Yucca Mountain for transit to and from target areas to the north. The area in the vicinity of Yucca Mountain is not a target area. The effects on a repository from overflights are increased noise, potential for aircraft crashes, and objects dropped from aircraft. The EA acknowledged that discussions with the USAF were ongoing at that time and that no irreconcilable conflicts were present.

3.3.1.4.5.2 Summary of Environmental Assessment Findings for the Disqualifying Condition for Offsite Installations and Operations

The EA evaluation for the disqualifying condition was similar to that for the qualifying condition in that it focused on the potential for underground nuclear explosions to impact repository operations. No problems were identified with ground-motion effects or with airborne releases. The logic used in supporting a lower-level suitability finding was that since the NTS activities would only cause short disruptions to normal repository operations (evacuation of the underground area during a UNE) and that other effects could be accommodated through design, no conflict would result with atomic energy defense activities.

3.3.1.4.5.3 Information Obtained since the Environmental Assessment for Offsite Installations and Operations

The following are major studies performed since the EA that have a bearing on the evaluation of the Offsite Installations and Operations Guidelines:

Repository Conceptual Design Studies. In the Repository Conceptual Design Report, prepared to support the Site Characterization Plan (DOE, 1988a), Sandia National Laboratory (SNL) (1987) revised estimates of radiological releases from accidents that could occur at the repository. Estimates in this study were made taking less credit for release mitigation systems (e.g., filters) than the EA. For this reason, higher doses to the maximally exposed individual (up to 1.1 rem) were estimated. At the same time, updated accident frequencies are lower than those presented in the EA. When frequency and consequences are combined to predict risk levels (frequency times consequences), both reports predict risks due to accidents are low for the waste handling building.

Preclosure Seismic Analysis of the Repository Surface Facility. Subramanian et al. (1989) evaluated trade-offs in seismic design standards for the repository surface facility and updated radiological release and frequency estimates from the EA. Results indicated that the facility is robust in response to ground motion. Releases of radioactive material are not likely, even if ground motion exceeds the design value of 0.4g.

Evaluation of Aircraft Overflights. Science Applications International Corporation (SAIC) (1987) expanded on the EA evaluation of aircraft frequency and radiological release estimates. Frequencies were generally higher than those presented in the EA, while accident consequences were generally lower than in the EA (Ma et al., 1991). This information was used in negotiations with the U.S. Air Force for land access for site characterization activities. These negotiations were successful in demonstrating cooperation with a neighbor of the Yucca Mountain site (Courtier, 1989).

Evaluation of Impacts from Defense Activities on the State of Nevada. A study by SAIC/Desert Research Institute (DRI) (1991) was funded by the Department of Defense as part of the approval process for continued land access for the Nellis Bombing and Gunnery Range. The study provides an indication of the variety of effects that Yucca Mountain site neighbors could have on the repository.

Site Restoration Plans for the NTS. Documents have been prepared that define the future of waste management and clean-up activities at the NTS (DOE, 1990h). These activities will expand the data base for estimating potential releases from the NTS. Also, the issue of water contamination was raised, which was not considered in the EA.

3.3.1.4.5.4 Review of Information Related to the Qualifying Condition for Offsite Installations and Operations

The following topics are relevant to evaluation of the qualifying condition for Offsite Installations and Operations:

Ground motion

Recent seismic evaluations (Subramanian et al., 1989) continue to support the conclusion that ground motion at Yucca Mountain due to UNEs will be less than that caused by natural events. Studies of potential ground motion at locations 19 miles from UNEs were reviewed in SAIC/DRI (1991), and current estimates of ground motion are on the order of 0.029g. This ground motion is considerably lower than the estimate quoted in the EA (see Section 3.3.1.4.4.1 of this report) because different assumptions were made about the size and location of future UNEs. No adverse effects on preclosure repository activities are expected from UNE-induced ground motion.

Air quality

Air emissions from the NTS, the TTR, and mining activities originate from concrete batch plants, aggregate crushing and processing, surface disturbance, fire training exercises, motor vehicle operations, boilers, fuel storage, and intermittent operations (SAIC/DRI, 1991). These emission sources are distributed over a large area and are operated in compliance with air emission permits. Thus, no adverse effects on preclosure repository activities are expected from these activities.

Water quality

There are two potential sources of water contamination that could affect repository preclosure activities: (1) migration of underground contamination from UNEs, and (2) surface flooding that would mobilize surface contaminants, if present. Detailed ground-water travel-time discussions are presented in Section 2.3.1.

Mobilization of surface contaminants upstream from the repository site in the Fortymile Wash drainage area is possible if such contaminants exist and if a flood were to occur. While detailed evaluations of this effect are not available, it can be mitigated, if necessary, through the use of reasonably available flood-water containment and treatment technology. No connection between the TTR and the Yucca Mountain site is known through which water quality at the Yucca Mountain site could be affected. No adverse effects on preclosure repository activities are expected from this effect.

Ionizing radiation

The NTS and the TTR have both used radioactive materials in their missions. There is little, if any, potential for releases from the TTR that could affect the Yucca Mountain site because of the separation of the sites. Recent estimates of expected releases from the NTS are predicted to result in exposure to a maximally exposed individual during the preclosure phase of the repository of less than 5 mrem per year (SAIC/DRI, 1991). These releases would neither adversely affect repository operations nor are they likely to exceed applicable regulations when added to repository releases. Technology exists to control repository releases to levels that would not exceed applicable regulations and standards.

Non-ionizing radiation

Radio frequency and laser emissions emanate from activities in the vicinity of the Yucca Mountain site. These emissions are controlled to applicable standards (SAIC/DRI, 1991). No adverse effects on preclosure repository activities are expected from this effect.

Solid and hazardous waste

Facilities handling radioactive and hazardous waste exist on the NTS, the TTR (SAIC/DRI, 1991), and at mining operations in the region. These activities are conducted under applicable regulations and are widely separated from the Yucca Mountain site. No adverse effects on preclosure repository activities are expected from this effect.

Noise and sonic boom

Aircraft overflights of the Yucca Mountain site and the NTS are restricted to subsonic speeds (SAIC/DRI, 1991). Noise from overflights can be mitigated, if necessary, by administrative procedures like those used during site characterization (Courtier, 1989). Noise-generating activities are conducted at the TTR, but the TTR is sufficiently separated from Yucca Mountain to preclude adverse effects. No other significant sources of noise are known in the vicinity of the site. No adverse effects on preclosure repository activities are expected from this effect.

Facility accidents

Both the NTS and the TTR use and store significant quantities of explosives, munitions, propellants, and hazardous materials (SAIC/DRI, 1991). Nearby mines may use explosive and fuel materials. These facilities are operated to applicable regulations and are sufficiently distant from Yucca Mountain to preclude adverse effects from facility accidents resulting in explosions, fires, or toxic releases. No adverse effects on preclosure repository activities are expected from this effect.

Releases of significant quantities of radioactive material

Releases from the NTS under accident conditions are not expected to exceed offsite doses of 500 mrem (SAIC/DRI, 1991). This could present a problem for continued operations of the potential repository if the radiation reached the repository site, but these levels are only 10 percent of the allowable exposure for radiation facility workers. Existing monitoring systems and emergency response procedures on the NTS would preclude any significant hazard to workers at the Yucca Mountain site.

If, in the unlikely event that accidents with maximum consequences were to occur simultaneously at the NTS and Yucca Mountain, then the combined accident exposure would have the potential to exceed the 500 mrem threshold. This is not considered likely because of (a) design standards for the repository to mitigate common-cause factors, such as earthquakes, in accident initiation and propagation and (b) the large distances between the NTS and Yucca Mountain activities. If detailed analysis shows a significant potential for simultaneous accidents, engineering and administrative means are available for mitigating the hazard.

No adverse effects on preclosure repository activities are expected from this effect.

Aircraft mishaps

Since the EA was published, the potential frequencies and consequences of aircraft crashes have been evaluated. Results of the investigations indicate that the likelihood of accidents with the potential to result in doses in excess of 500 mrem is less than 1 in 1,000,000 per year (SAIC, 1987; Ma et al., 1991). The studies concluded that an aircraft accident would not pose a hazard to the public due to a resultant radiation release. This does not suggest that a crash on the site, however, would not disrupt repository operations. A crash on the site is predicted to be a rare event with a frequency of 1 in 100,000 per year (SAIC, 1987). This level of hazard to operations is not believed to be significant, and it can be further mitigated using agreements like the one made with the USAF for land access during site characterization (Courtier, 1989). No adverse effects on preclosure repository activities are expected from this effect.

Objects dropped from aircraft

Armaments and other objects could be dropped from aircraft overflying the Yucca Mountain site. Rates in the Nellis Range complex are 0.005 armament drops per 1,000 sorties and 1.5 objects per 1,000 sorties (SAIC/DRI, 1991). The 1987 value of 28,000 overflights for the Yucca Mountain site (SAIC, 1987) represents a significant annual frequency of dropped objects. However, the frequency of dropped objects in flight is not a good predictor of the frequency of potential objects hitting the site. This is because the flight paths are hundreds of miles long, most objects are ejected on takeoff, and special precautions are taken with flights using armaments (SAIC, 1987).

The potential to disrupt operations depends on the object dropped. The consequences of objects such as bolts, sheet metal, or canopies hitting the site would be negligible and nondisruptive. The drop of a 2,000 pound bomb could disrupt operations for a significant period and has the potential to release radioactive material. While a detailed evaluation of dropped armaments has not been performed, this effect can be mitigated, if needed, through airspace agreements like the one negotiated for site characterization (Courtier, 1989), or by other administrative controls. Examples of possible controls include rerouting aircraft, pilot training, beacons, and repository facility hardening.

No adverse effects on preclosure repository activities are expected from this effect.

Transportation of hazardous materials

Both US Highway 95 (12 miles from the site) and roads on the NTS and the TTR are used to haul significant quantities of explosives, munitions, propellants, and hazardous and radioactive materials. These materials are shipped in compliance with applicable regulations and sufficiently distant from Yucca Mountain to preclude adverse effects from transportation accidents resulting in explosions, fires, or toxic releases. Some materials of this type will also be transported to the site for use by the DOE repository program if the repository is licensed for construction. Effects from potential transportation accidents enroute to the site will be considered in the repository surface facility design and, if necessary, potential hazards will be mitigated using existing technology. No adverse effects on preclosure repository activities are expected from this effect.

3.3.1.4.5.5 Review of Information Related to the Disqualifying Condition for Offsite Installations and Operations

In the following text, potential effects are discussed from the perspective of the effects the repository could have on neighboring activities. Effects that neighboring activities could have on the repository are discussed under the qualifying condition evaluation. Offsite activities reviewed here are those defined previously as atomic energy defense activities:

Air quality

Air emissions from the potential repository would originate from concrete batch plants, aggregate crushing and processing, surface disturbance, motor vehicle operations, boilers, fuel storage, and intermittent operations. These emission sources would be a large distance from neighboring activities and would be operated in compliance with air emission permits. Air-quality impacts from the potential repository are not expected to lead to an irreconcilable conflict with atomic energy defense activities.

Water quality

There are no planned untreated emissions of water from the potential repository. Water-quality impacts will not lead to an irreconcilable conflict with atomic energy defense activities.

Ionizing radiation

The potential repository would be handling, storing, and disposing of large quantities of radioactive material. The facility will be designed to meet applicable requirements for protection of both worker and public health and safety. Releases of radioactive material and radiation from the potential repository are expected to be minor, and will be less than applicable regulations and standards. However, specific estimates for these releases have not been completed. During future design activities, these releases will be evaluated and mitigation technology applied such that ionizing radiation is not expected to lead to an irreconcilable conflict with atomic energy defense activities.

Non-ionizing radiation

Radio-frequency emissions emanate from activities on the Yucca Mountain site. These emissions are controlled to applicable standards in cooperation with other federal users of this resource. Non-ionizing emissions from the repository will not lead to an irreconcilable conflict with atomic energy defense activities.

Solid and hazardous waste

Facilities for handling radioactive and hazardous waste would be constructed on the Yucca Mountain site. These facilities will be operated under applicable regulations and are widely separated from atomic energy defense activities. These activities will not lead to an irreconcilable conflict with atomic energy defense activities.

Noise and sonic boom

Activities at the Yucca Mountain site are not expected to generate unusual amounts of noise compared with similar mining and material handling activities. Noise emissions will be controlled to applicable standards, and the site is sufficiently separated from atomic energy defense activities to preclude irreconcilable conflicts.

Facility accidents

The potential repository site may store and use significant quantities of explosives, propellants, and hazardous materials. These facilities would be operated to applicable regulations and are sufficiently distant from offsite activities to preclude irreconcilable conflict with atomic energy defense activities.

Releases of significant quantities of radioactive material

Repository surface facility design standards require that releases under accident conditions will not exceed offsite doses of 500 mrem. These levels represents 10 percent of the allowable exposure for radiation facility workers. Existing monitoring systems and emergency-response procedures on the NTS would be expected preclude any significant hazard. Hazards at the TTR would be less than the NTS because of the distance to the facilities. Aircraft operations would likely be precluded during an accident. Accidents of this type are expected to be rare and not lead to an irreconcilable conflict with atomic energy defense activities.

Transportation of hazardous materials

Both US Highway 95 (12 miles from the site) and roads on the NTS will be used to supply the potential repository with significant quantities of explosives and hazardous materials. Shipments of these materials will be conducted in compliance with applicable regulations and are sufficiently distant from atomic energy defense activities to preclude irreconcilable conflict with atomic energy defense activities.

Security

A potential repository at Yucca Mountain would need to comply with both NTS and NRC requirements for security. Security effectiveness is likely to be similar at Yucca Mountain to other areas of the NTS. This, coupled with large distances from Yucca Mountain to other activities on the Nellis Range Complex, supports the conclusion that security will not lead to an irreconcilable conflict with atomic energy defense activities.

Use of scarce resources needed for continued mission support

Scarce resources in the area of Yucca Mountain that are needed by offsite facilities include water and controlled airspace. Water is discussed in Section 3.3.2.2 and is not discussed here. Airspace agreements have been successfully negotiated between the Nellis Range and the NTS (Courtier, 1989). In addition, the Nellis Range is not an atomic energy defense activity. Competition for scarce resources is not likely to lead to an irreconcilable conflict with atomic energy defense activities.

3.3.1.4.6 Conclusions and Recommendations for Future Activities for Offsite Installations and Operations

The previous discussion indicates there is no reason to believe that the design of the facilities at the site will not be able to accommodate potential adverse effects of offsite installations and operations for both the qualifying and disqualifying conditions.

For the disqualifying condition, it is the consensus of the Core Team that future information is unlikely to demonstrate that repository siting, construction, operation, closure, or decommissioning will conflict irreconcilably with atomic energy defense activities in proximity to the site. Thus, a higher-level suitability finding (Level 2) is supported for the disqualifying condition for Offsite Operations and Installations.

For the qualifying condition, the consensus of the Core Team is that information available now or in the future is not likely to show significant adverse effects from nearby industrial, transportation, and military installations and operations, including atomic energy defense activities, that cannot be accommodated by engineering measures. Similarly, emissions from offsite facilities considered together with emissions from repository operations and closure are not likely to lead to unacceptable releases. However, the level of detail and inconsistencies in the available data base for radioactive material releases do not provide adequate confidence to support a higher-level suitability finding for this qualifying condition at this time. The Core Team therefore continues to support the lower-level suitability finding (Level 3) for this qualifying condition.

Discussion

The Core Team has assumed that interagency cooperation among appropriate entities will occur as necessary for the DOE to follow the mandate given to them by Congress in the NWPAA (1987). The NWPAA (1987) directs other agencies to expedite the necessary arrangements and agreements. Continuing cooperation and accommodation will be necessary for the conclusions about this guideline to remain valid.

3.3.1.5 EVALUATION OF THE SYSTEM GUIDELINE FOR RADIOLOGICAL SAFETY

Qualifying Condition [10 CFR 960.5-1(a)(1)]: "Any projected radiological exposures of the general public and any projected releases of radioactive materials to restricted and unrestricted areas during repository operation and closure shall meet the applicable safety requirements set forth in 10 CFR Part 20, 10 CFR Part 60, and 40 CFR 191, Subpart A (see Appendix II of this part)."

3.3.1.5.1 Description of Radiological Safety System Guideline

The qualifying condition for this guideline invokes the requirements of 10 CFR Part 60, 40 CFR 191 Subpart A, and 10 CFR Part 20. Further details of this applicability are discussed in Appendix II of 10 CFR Part 960.

Requirements regarding preclosure radiological protection are specified in 10 CFR 60.111. This regulation invokes 10 CFR Part 20 and "such generally applicable environmental standards for radioactivity as may have been established by the Environmental Protection Agency," herein assumed to represent 40 CFR 191, Subpart A. Requirements for retrievability are also set forth [10 CFR 60.111(b), and see also 10 CFR Part 960, Appendix II].

Environmental standards for preclosure operation of a commercial high-level radioactive waste repository (regulated by the NRC) and defense high-level or transuranic waste repositories, such as the Waste Isolation Pilot Plant (not regulated by the NRC) are provided in 40 CFR 191, Subpart A. These standards restrict combined doses from the repository and other fuel-cycle activities licensed under 40 CFR Part 190 to not exceed 25 mrem to the whole body, 75 mrem to the thyroid, or 25 mrem to any other critical organ. Activities on the NTS and elsewhere that are not licensed by the NRC are not included in the 40 CFR Part 191 limits for the repository.

Worker radiological exposure is regulated by 10 CFR Part 20. This regulation also sets a dose limit of 0.1 rem for any individual member of the public from an NRC-licensed operation. Compliance with 40 CFR 191, Subpart A, will also satisfy the 10 CFR Part 20 limit. The regulation specifies maximum concentrations of radionuclides and dose rates that may be present outside the boundary of the restricted area. While compliance with 40 CFR Part 191 will maintain average concentrations well below these maximum limits, the limits will apply in the evaluation of abnormal operations and accidental releases.

For 10 CFR Part 60, the Nuclear Regulatory Commission (NRC) requires that structures, systems, and components important to safety (that is, important to prevention or mitigation of release of radionuclides during abnormal operations or accidents) be subject to quality assurance controls and additional design considerations. These controls are intended to increase assurance of the safe operation of the repository during normal and abnormal operations. In 10 CFR Part 60, the NRC makes no provision for a limiting accidental dose as is done for other NRC-licensed facilities. The DOE has requested the adoption of a limiting dose in 10 CFR Part 60.

3.3.1.5.2 Approach for Radiological Safety System Guideline Evaluation

As noted in the EA (DOE, 1986), the following elements must be defined to complete the evaluation for this guideline: (1) the engineered components that function to control releases of radioactive materials, (2) site-specific conditions that may contribute to initiation of releases of radioactive materials, (3) site characteristics that affect radionuclide transport, and (4) location of individuals and the distribution of people subjected to exposure from the release.

Data and evaluations for the Meteorology and Population Density and Distribution Technical Guidelines will also resolve the issues for items (3) and (4) above. Likewise, data from the Offsite Installations and Operations Technical Guideline will contribute to the evaluation of external events that may initiate or influence releases from the potential repository [item (2) above]. A system-wide evaluation including these four elements can determine whether the system could satisfy the guideline. Section 3.3.1 provides further discussion of the approach to evaluation of this System Guideline.

The design of the engineered components of the repository would include features to control normal operational effluents and to prevent or mitigate accidental releases of radionuclides. The design of the repository is expected to address site-specific features, program requirements, and operating strategies that will affect preclosure safety. Source terms describing the quantities and characteristics of radioactive materials for normal operations and accidents will be derived for the repository design.

The issues and information from the system elements described in this section serve as the basis for the evaluation of compliance with the regulations related to the Preclosure Radiological Safety System Guideline. Analysis techniques accepted for use in evaluating nuclear power reactors may also be used in this evaluation. Suitability under this guideline is assumed to be established by including repository design features that provide reasonable assurance that the preclosure regulatory requirements are met.

3.3.1.5.3 Status of Current Information for Radiological Safety System Guideline

The preliminary evaluation of the system elements pertinent to this guideline shows that the characteristics of the site favor its ability to limit worker and public exposure to radiation. Estimates of both accidental exposures to the general public and exposures due to normal operation are below the limits specified in 10 CFR Part 20 and 40 CFR 191, Subpart A. Estimated releases under normal repository operation produce radionuclide concentrations that are well below the maximum permissible concentrations (DOE, 1986). As reported in the EA, the evidence did not support a finding that the site is not likely to meet the qualifying condition for the Preclosure System Guideline.

The EA evaluation of preclosure radiological safety under accidental conditions was based on a preliminary safety assessment (Jackson et al., 1984). Jackson et al. (1984) adopted release characteristics and scenario information from generic studies of nuclear facilities. This approach allowed a numerical evaluation in the absence of detailed repository design data.

The most significant repository design effort since the preparation of the EA is the Repository Conceptual Design Report (SCP-CDR)(SNL, 1987), prepared to support development of the SCP. The SCP-CDR provided proposed locations and areal extent of underground and surface facilities and helped identify the parameters and information to be collected by site characterization studies. Because of the logical connection to site characterization studies, emphasis was placed upon underground facility design issues. Surface facility design efforts addressed site characterization data needs and preliminary safety evaluations needed for guidance of future design activities.

Studies of preclosure accident safety have been completed to support development of the Quality List, or list of engineered items subject to quality-assurance controls. The SCP-CDR (SNL, 1987) and a report, titled "Identification of Structures, Systems, and Components Important to Safety at the Yucca Mountain Repository," (Hartman and Miller, 1991) provide evaluations reflecting the design configuration cited in the SCP. The purpose of these evaluations is to identify items that initiate accidents or that may mitigate accidents, so that quality assurance programs may be applied to their design, acquisition, and operation. Items with unfavorable impacts on safety may either be redesigned to enhance safety features or eliminated through changes in facility configuration. Successive iterations of design and preclosure accident safety evaluations will lead to assurance that the final design will function to prevent or mitigate accidents. Future evaluations of suitability with respect to the System Guideline will depend on these evaluations.

To better understand the seismic interface between facilities and site properties, Subramanian (1989) evaluated trade-offs in seismic design standards for the repository surface facility, updated release estimates for radioactive gases and particulates, and revised event frequency estimates. Results indicate that facilities may be designed to withstand the expected ground motion at the Yucca Mountain site, using reasonably available technology. Unacceptable releases of radioactive material from the SCP-CDR surface facilities are not likely even if ground motion exceeds the SCP-CDR design basis of 0.4g.

New preclosure safety assessments of military aircraft impact scenarios have been completed since publication of the EA and were discussed in Section 3.3.1.4., the Offsite Installations and Operations Guideline evaluation. These assessments serve as the basis for updated evaluations of preclosure accident safety for this guideline and must be addressed in repository design.

Much of the technology to be applied to the repository was developed for service in reprocessing facilities where particulate and gaseous releases are controlled when spent fuel is dismantled, crushed, and dissolved. Current goals for repository operations will be to package spent fuel with minimal handling and without damage to the fuel. By nature, the repository environment should be less challenging to effluent control systems than facilities that reprocess fuel or that have to provide active cooling of spent fuel. The difference between the protection offered by control technology versus the nature of repository operations implies that there can be confidence that radiation protection standards can be met before the details of the facility design are established.

A decision to dispose of intact spent fuel will benefit preclosure safety of the repository by eliminating the equipment and processing steps associated with spent fuel consolidation. Because much of normal repository operational effluent is associated with fuel damage during consolidation, elimination of consolidation would enhance repository compliance with Part A of 40 CFR 191 as well.

Information developed since publication of the EA has not adversely altered the conclusions of the EA regarding site suitability under this System Guideline. With the absence of extreme influences from offsite facilities and activities, the repository design process should be sufficient to address the issues in the Preclosure Radiological Safety Guideline. Site conditions do not appear to place undue constraints on designs needed to meet radiological safety requirements. However, detailed designs and documentation supporting this conclusion will not be available until advanced stages of repository design are completed.

3.3.1.5.4 Conclusions and Recommendations for Future Activities for Radiological Safety System Guideline

The consensus of the Core Team is that current information continues to support a lower-level (Level 3) suitability finding for this System Guideline. This guideline is a composite of the system elements identified in the Technical Guidelines and the engineered facilities of the preclosure repository. The Core Team is of the opinion that the attributes of the site-related system elements addressed by the Technical Guidelines could support a higher-level suitability finding. However, the absence of more detailed design information precludes the team from supporting a higher-level suitability finding for the System Guideline at this time.

Discussion

Design decisions and actions related to configuration of the repository (e.g., allocation of functions between the repository and the MRS, waste package design characteristics, final decisions on fuel-rod consolidation, fuel burn-up and aging, and waste-emplacement orientation) will provide additional information relevant to evaluating preclosure radiological safety. No further site-related activities are recommended to evaluate suitability with regard to this guideline. However, various data gathering activities will provide useful confirmatory information, especially for dose assessment modeling and calculations for the proposed facility.

3.3.2 EVALUATION OF GUIDELINES FOR ENVIRONMENTAL QUALITY, SOCIOECONOMIC IMPACTS, AND TRANSPORTATION

Collectively, these guidelines are intended to protect the public and the environment from all potential impacts of the repository before closure. The qualifying condition for the System Guideline requires:

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

The phrase "hazards posed by" covers not only the potential radiological impacts of waste handling, but also all potential impacts on resources of the area. For example, potential hazards to flora and fauna from siting activities, radiological hazards associated with transportation, and adverse effects on site features of historical significance are considered in evaluating this group of guidelines.

The technical guidelines for this System Guideline are Environmental Quality (960.5-2-5), Socioeconomic Impacts (960.5-2-6), and Transportation (960.5-2-7). Evaluations of these guidelines are presented in Sections 3.3.2.1 through 3.3.2.3.

The approach for evaluating the guidelines in this group is to conduct the activities necessary to develop an understanding of the range of potential adverse impacts and an understanding of the extent to which significant adverse impacts can be mitigated. The types of impacts that are to be considered in the Environmental Quality, Socioeconomic, and Transportation areas have not yet been defined, although by using current site information and experience on other federal programs, the impacts that are likely to be of concern can be identified. If the available information supports a finding that these impacts will not be significant, or can be acceptably mitigated, then at least a lower-level suitability finding can be supported.

As described in Section 1.2.4, a conclusion that a higher-level suitability finding can be supported requires that all members of the Core Team agree that new information is unlikely to change the lower-level suitability finding for a specific qualifying or disqualifying condition. Because the types of impacts that will need to be evaluated for this group of guidelines have not yet been fully defined, the specific levels of measures necessary to mitigate significant adverse impacts are not yet established. The ongoing programs to address environmental quality, socioeconomic, and transportation issues and concerns indicate that some types of impacts have been identified and are being assessed. However, additional information concerning the environmental characteristics of the site and repository design, as well as ongoing input from State and local officials and from residents of Nevada is believed to be necessary to fully define the types of impacts that are to be addressed.

3.3.2.1 ENVIRONMENTAL QUALITY TECHNICAL GUIDELINE

3.3.2.1.1 Statement and Discussion of the Qualifying and Disqualifying Conditions

Qualifying Condition [10 CFR 960.5-2-5(a)]: "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."

Disqualifying Conditions [10 CFR 960.5-2-5(d)]: "Any of the following conditions shall disqualify a site:

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

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

3. The presence of the restricted area or the repository support facilities would conflict irreconcilably with the previously designated resource-preservation use of a component of the National Park System, the National Wildlife Refuge System, the National Wilderness Preservation System, 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."

Discussion. Because this guideline is termed "environmental quality," it is somewhat open to interpretation as to which environmental disciplines should be included in the analysis for the qualifying condition. The disciplines that are expected to be included for eventual site suitability determinations consist of air quality, cultural resources, terrestrial ecosystems, soils, radiological studies, aesthetics, noise, water resources, and land use. The water resources environmental discipline is not included in this evaluation because it appears as a separate disqualifying condition under the Socioeconomic Impacts Technical Guideline [10 CFR 960.5-2-6(d)]; however, it is considered as part of the environmental evaluation program. The land use discipline is evaluated mainly with regard to "special use" parcels of land that are federally protected and is addressed in the second and third disqualifying conditions of this technical guideline.

Evaluating environmental site suitability under this guideline is taken to mean evaluating the impacts on environmental parameters that could result from siting and operating a repository at Yucca Mountain. The DOE's environmental program is studying the site with respect to two very distinct phases: site characterization and repository development. All data-gathering activities to date have been designed to address possible impacts from the conduct of site characterization activities. Much of the data will be used as environmental baseline information for identifying impacts if the repository program continues into the development phase. According to the Nuclear Waste Policy Act (NWPA, 1983), the repository development phase will require that the process defined in the National Environmental Policy Act (NEPA, 1969) be followed.

Disqualifying condition 1 is essentially identical to the qualifying condition except that it is stated in reverse for disqualification and qualification purposes. All suitability evaluations for these two conditions are identical and are discussed together for the remainder of the evaluation.

Disqualifying conditions 2 and 3 were included in the guidelines to ensure protection of "special use" lands from direct siting of repository-related facilities on these parcels and to protect such lands from any potential impacts of operations conducted under the repository program.

3.3.2.1.2 Approach for Environmental Quality Guideline Evaluation

The approach for evaluating this guideline is to conduct the activities necessary to develop an understanding of (a) the range of potential adverse environmental impacts and (b) the extent to which significant adverse impacts can be mitigated. The types of impacts to be considered for the Environmental Quality Guideline have not yet been defined, although by using current site information and experience on other similar federal or private programs, the impacts that are likely to be of concern can be identified. If the available information supports a finding that these impacts will not be significant, or can be acceptably mitigated, then at least a lower-level suitability finding can be supported.

As described in Section 1.2.4, a conclusion that a higher-level suitability finding can be supported requires that all members of the Core Team agree that new information is unlikely to change the lower-level suitability finding. Because the types of environmental impacts that will need to be evaluated have not yet been fully defined, the specific levels of measures necessary to mitigate significant adverse impacts are not yet established. Although it is possible to estimate such impacts and mitigation measures, this approach was not followed at this time because of uncertainties in environmental information for the site and the conceptual nature of current repository designs.

3.3.2.1.3 Status of Current Information for Environmental Quality

The environmental disciplines listed below are part of the supporting information for evaluations of the qualifying condition and disqualifying condition 1 for this guideline. Also listed in this section are discussions for disqualifying conditions 2 and 3. The Environmental Assessment (EA) (DOE, 1986) stated the case for lower-level suitability findings for each of the conditions addressed by this guideline. That is, the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3) and the evidence does not support a finding that the site is disqualified (Level 1) for the disqualifying conditions.

3.3.2.1.3.1 Status for Qualifying Condition and Disqualifying Condition 1 for Environmental Quality

Air Quality

Statements were made in the Environmental Assessment (EA) (DOE, 1986) that the existing air quality was expected to be "very good." This designation indicates that the levels of criteria air pollutants were expected to be well below applicable ambient air quality standards. The statements were based on data taken at similar locations in southern Nevada and nearby areas. The air quality monitoring performed thus far has generally borne out the statements made in the EA.

Meteorological conditions in the area are addressed by a separate qualifying condition, but deserve mention here because of their significant role in the estimation of air quality impacts. Preliminary analyses of the meteorological monitoring data indicate that dispersion characteristics of the area are sufficient to ensure that air quality impacts remain within acceptable levels as required by the standards enumerated in the Federal Clean Air Act (CAA, 1990). Radioactive air emissions are addressed by U.S. Environmental Protection Agency regulations and are the subject of preclosure radiological safety requirements of 10 Part CFR 960 presented in Section 3.3.1.

Cultural Resources

The potential for adverse effects to archaeological resources caused by DOE activities was determined by performing literature reviews, intensive surveys to identify resources in the Yucca Mountain area, and limited test excavations at selected archaeological sites. Literature reviews included an annotated bibliography of the archaeological and historical literature of the Yucca Mountain region (Pippin and Zerga, 1981a), and an overview of known archaeological and historical resources (Pippin and Zerga, 1981b).

An intensive survey of over 7,000 acres of the main Yucca Mountain area was also undertaken to identify, in more detail, the nature and expected distribution of archaeological resources (Pippin et al., 1982). In addition, numerous short preactivity surveys were conducted and reports were prepared during this time. Also, limited test excavations were also conducted at 29 archaeological sites to determine if they contained buried cultural materials (Pippin, 1984). These studies identified over 180 prehistoric and historic cultural resources in the area, including prehistoric temporary camps, transient water sources (tinajas), toolstone quarries, lithic scatters, milling stations, caches, and isolated artifacts. Historic materials included two major trails, cairns, isolated tin cans, and one prospector's temporary camp. These sites indicated that the Yucca Mountain region had been occupied by people for over 10,000 years, using a variety of subsistence and settlement practices and organizations.

Approximately half the sites noted at the time were considered eligible for nomination to the National Register for Historic Places, and of these, over 40 sites were located in areas then considered to be subject to repository-related disturbances. These cultural resources were judged important for understanding the history and prehistory of the region, and it was recommended that DOE activities should avoid adverse effects on archaeological resources by modifying activities or by conducting mitigative data recovery at archaeological sites that were subject to adverse effects.

In the EA, favorable conditions for locating the repository at Yucca Mountain included (1) the projected ability to meet Federal, State, and local requirements concerning protection of cultural resources and (2) significant adverse effects to cultural resources that could be mitigated to an acceptable degree. On the basis of the results of the archaeological studies conducted, both favorable conditions could be projected to be present at Yucca Mountain. No unfavorable conditions were projected to be present at Yucca Mountain on the basis of the same archaeological studies. These conclusions were sufficient to support a finding that the site was not expected to be disqualified on the basis of adverse effects of DOE activities on cultural resources in the area.

Since the EA, substantial progress has been made in establishing the process by which the DOE will comply with the National Historic Preservation Act (NHPA, 1966) and other federal regulations. The DOE has entered into a Programmatic Agreement with the Advisory Council on Historic Preservation (ACHP) that stipulates the measures necessary for compliance (DOE, 1988d). Among the terms of the Programmatic Agreement are the identification and evaluation of cultural resources in areas where planned activities may potentially damage archaeological resources, data recovery to mitigate unavoidable damage to cultural resources by DOE activities, development of a research design and data recovery plan for treatment of archaeological resources, and a worker education program.

Numerous additional archaeological inventory surveys and mitigative data recovery projects have been conducted before potentially disturbing activities are initiated. These surveys and projects have resulted in a large corpus of additional data concerning the nature, frequency, distribution, and significance of cultural resources potentially affected by DOE activities. In total, over 12,000 acres have been surveyed in the Yucca Mountain region, and nearly 600 archaeological sites have been discovered. The majority of the archaeological materials have been recognized by the DOE as eligible for nomination to the National Register of Historic Places as an archaeological district (DOE, 1990g). Regulatory provisions of the NHPA require protection of archaeological properties eligible for nomination to the National Register.

A Programmatic Agreement for the repository phase of the program is not yet in place; however, it is assumed that any potential damage to sites can be mitigated through field study and data recovery. The potential siting of a repository at Yucca Mountain is not expected to be impacted by this compliance process.

Associated with the cultural resource study program is a Native American consultation and study effort that addresses the cultural and religious values and beliefs of the Yucca Mountain area. The DOE, in consultation with Tribal Councils and key cultural experts from Western Shoshone and Southern Paiute tribes and other Native American groups, has been conducting studies that identify to what extent traditional cultural and religious values are associated with specific Yucca Mountain Project areas. Components of the effort include interpretation of cultural resources, ethnohistory of Native American people, spatial analysis of cultural resources, and ethnographic characteristics of Native American plant uses (Stoffle et al., 1990b). Strategies to minimize the effects on these values, beliefs, and cultural resources need to be developed in consultation with the Native Americans.

Terrestrial Ecosystems

When the EA was prepared, no threatened or endangered species had been identified at Yucca Mountain, although two indigenous species were under consideration for protection. Ash Meadows, located about 25 miles south of Yucca Mountain, was evaluated because it is a unique area with several resident protected species. No data suggested, however, that any threatened or endangered species or critical habitat, would be significantly impacted by the DOE Site Characterization Program. The EA reported that impacts to Ash Meadows hydrology were not expected, based on analysis of studies by Dudley and Larson (1976) and Waddell (1982). Further studies of the hydrology are being conducted to confirm the earlier conclusions.

A literature review was performed to extract information describing the ecological characteristics of Yucca Mountain. The information collected served as a basis for conducting surveys of the biological resources of the area. Surveys were initiated in 1982 to characterize the plant and animal associations and communities at Yucca Mountain. Small mammals were trapped in each plant association to determine species composition of the community. Species of reptiles, birds, and mammals (other than small mammals) were also noted.

Transects were walked throughout the area of Yucca Mountain to determine the abundance of desert tortoise from 1982 through 1984. Tortoises and tortoise signs were counted and mapped. Data suggested that tortoise population densities were low throughout the area.

Surveys for plant species considered to be candidates for listing as "endangered or threatened" were also conducted throughout the area. Areas meeting habitat requirements of the species were intensively searched. Populations of fishhook cactus and other candidate species were mapped to ensure they would not be impacted by DOE activities.

The EA concluded that the site should not be disqualified (Level 1) based on potential impact to environmental quality with regard to biological resources. This finding was based on the status of the resources, activities to be conducted and their effects, and mitigation measures.

Since the EA, the desert tortoise was listed as a threatened species. No "critical habitat" was identified when the desert tortoise was listed. Actions have been taken to avoid or mitigate impacts to the desert tortoise and other important biological resources. The DOE entered into consultation with the U.S. Fish and Wildlife Service (FWS) after the desert tortoise was listed as a threatened species. A Biological Assessment was prepared by DOE as a part of this consultation. As a result, FWS rendered a "No Jeopardy" Biological Opinion (McNatt, 1990), stating that site characterization activities at Yucca Mountain should not jeopardize the species, if certain precautionary measures are taken. The DOE has implemented desert tortoise studies as stipulated in the Biological Opinion. These studies assist in managing activities and resources to minimize impacts to desert tortoises and include evaluating mitigation techniques such as relocation and reclamation. Preactivity surveys and studies of the distribution and population status of the tortoise and of the effects of DOE activities on the species are required.

The DOE has initiated reclamation feasibility studies to determine the most efficient methods for reclaiming areas disturbed by site characterization. These studies will evaluate plant species, planting methods, soil amendments, seedbed preparation methods, and other promising techniques. Additionally, methods for stabilization of topsoil stockpiles will be investigated. The most effective methods will be used to reclaim sites.

Additional future studies may include the evaluation of the effects of increased soil temperature on biological resources and monitoring terrestrial and aquatic communities at Ash Meadows. As indicated earlier, studies will need to be expanded to determine the effects of other phases of the DOE repository program. The general approaches for addressing issues associated with threatened and endangered species are assumed to continue to serve as the basis for the DOE's environmental program.

Information from ongoing studies of biological resources in the Yucca Mountain area is summarized in EG&G (1991). The objective of the ongoing studies is to determine the effects of site characterization activities on biological resources. Vegetation, insects, desert tortoises, other reptiles, small mammals (including spotted bats), and birds are among the biological resources being monitored. For at least one year, data has been collected for small mammal and desert tortoise populations and for vegetation.

Soils

The EA concluded that no significant adverse impacts would occur if management and engineering controls were implemented to control run-off and reduce erosion, to salvage and stockpile surface soils, and to reclaim disturbed areas.

During the preclosure time period, soil resources in the area are not expected to be significantly impacted. During the postclosure period, there is the possibility that the area immediately above the proposed repository will undergo an increase in soil temperature and decrease in soil moisture for a period of thousands of years (Ostler, 1991). This potential soil temperature change does not represent a significant impact because the change would be very localized.

No additional soils data have been collected since the EA. The Soil Conservation Service issued a finding to the DOE that no prime or unique farmlands are present near the Yucca Mountain site. This finding supports the lower-level suitability finding for this guideline with regard to soil resources.

Radiological Studies

In the EA, analyses were presented that compared potential releases of naturally occurring radionuclides to the environment (caused by site characterization activities) with estimates of releases of radionuclides from granite. Using the estimates of release of radioactive material from granite provides a bounding value because granite is likely to be higher in natural radioactivity than volcanic tuffs. However, values for releases that might occur during excavation at Yucca Mountain were not available. The EA concluded that impacts were expected to be minimal and within regulatory limits that were in place at that time.

A comprehensive radiological monitoring network has been established to monitor background radiological conditions in the Yucca Mountain area. The network is collecting data associated with airborne radionuclides (including radon), radionuclides in soils, ambient radiation, radionuclides in surface water and sediments, radionuclides in ground water, and radionuclides in biota. These data are being evaluated in relation to a circular grid centered approximately on the site of the proposed facilities and radiating out for approximately 84 km. Some information is presently available that did not exist at the time the EA was prepared; none of this information suggests that current regulatory criteria would not be met. Preclosure radiological safety evaluations with regard to accident and normal conditions are presented in Sections 3.3.1.1 and 3.3.1.5 of this report.

Aesthetics and Noise

The EA concluded that there would be a change in appearance of the Yucca Mountain area during the phases of the potential repository program. During construction of facilities, there would be temporary visual impacts caused by operations and equipment. After construction, there would be additional roads and facilities that may be visible from Highway 95; however, they would not be visible from major population centers or recreation areas. Overall, aesthetic impacts will be minimal.

Various levels of noise will be generated by construction and testing activities during site characterization and repository development. The EA described noise levels for equipment that may be used and for operations that may be conducted. No sustained significant increases in noise levels will occur or cause impacts to any major population center. Noise impacts on wildlife are not completely understood. The desert tortoise, a threatened species inhabiting the area, however, is not expected to be impacted by increased noise levels. The FWS stated in its Biological Opinion that the desert tortoise will not be significantly impacted by any site characterization activities, providing certain precautions are taken (McNatt, 1990).

An aesthetics survey was conducted as part of an Exploratory Studies Facility (ESF) alternatives evaluation (Stevens and Costin, 1991). That survey addressed potential aesthetic impacts associated with siting surface structures at Yucca Mountain. No significant adverse impacts were identified for the proposed site characterization ESF components. No additional information has been obtained because aesthetics and noise do not represent a concern with regard to impacts from site characterization activities. These subject areas will need to be more fully evaluated as part of the impact assessment activities for the repository phase of the program.

3.3.2.1.3.2 Status for Disqualifying Condition 2 for Environmental Quality

The EA stated that neither the restricted area nor the supporting facilities for a repository would be located within the boundaries of any of the parcels of land listed in this condition. That statement continues to be true for DOE's current designs and plans for facilities at Yucca Mountain, including the siting of a rail spur to the Yucca Mountain site. The rail spur options have been chosen consistent with avoiding impacts to federally protected lands.

Since the EA, administrative land boundaries have been constantly reviewed and tracked for any changes that may affect the repository program. However, none have occurred to date.

3.3.2.1.3.3 Status for Disqualifying Condition 3 for Environmental Quality

The EA identified the closest parcels of land that are part of the systems mentioned in this disqualifying condition. They include Death Valley National Monument, Ash Meadows (much of it is within the National Wildlife Refuge System), the Timber Mountain Caldera National Natural Landmark, and the Toiyabe National Forest. The EA stated that because of the distance between these parcels and the Yucca Mountain site, irreconcilable conflicts would not exist. In addition, it was stated that the outflows of springs in the Ash Meadows area would not be affected by water withdrawals for a repository program because the springs in Ash Meadows emerge from a different aquifer than the aquifer underlying Yucca Mountain. The statements made in the EA were accurate for the timeframe in which they were made, and they most likely remain valid.

It appears the only issues potentially linked to this disqualifying condition may be potential impacts to water resources in the Ash Meadows area. Monitoring of Devils Hole and the springs at Ash Meadows have been included in the DOE's environmental water resources monitoring program developed in consultation with the National Park Service (NPS) (DOE, 1991c). Devils Hole is a detached unit of Death Valley National Monument and is controlled by the NPS. Much of Ash Meadows lies within a National Wildlife Refuge and is managed by the United States Fish and Wildlife Service. The monitoring program was designed in response to an NPS protest to the DOE application for a water appropriation permit from the State of Nevada. The protest was filed so that the NPS could protect their water rights in areas over which they have jurisdiction. The Core Team understands that the NPS has protested other water appropriation permit applications in the area as well. Even though the potential repository is not expected to impact water resources located down-gradient in separate aquifers and ground-water basins, a plan was prepared to address the concerns raised (DOE, 1991c). Data collected according to this plan will need to be analyzed to assess potential impacts in the Ash Meadows area.

3.3.2.1.4 Conclusions and Recommendations for Future Environmental Quality Activities

Disqualifying Condition 1 and Qualifying Condition. The consensus of the Core Team is that available information continues to support the lower-level suitability findings for disqualifying condition 1 (Level 1) and for the qualifying condition (Level 3) for the Environmental Quality Guideline. Uncertainties about the range of potential environmental impacts and the mitigation measures that may be needed to avoid significant impacts, do not allow a higher-level suitability finding to be supported at this time, although available evidence for the Yucca Mountain site suggests that potential environmental impacts can be acceptably mitigated.

Disqualifying Condition 2. Current DOE plans indicate that none of the planned repository support facilities (including the rail spur options) or the restricted area would be located within parcels of land listed in disqualifying condition 2. The DOE maintains positive control over those lands that will be used for many of the site characterization activities and is expected to pursue appropriate land withdrawal legislation if the site is chosen for a repository. Tracking of administrative land boundaries will need to continue with regard to the siting of support facilities (especially planned rail-spur routes) for verification of the higher-level finding in the future. On the basis of this information, the consensus of the Core Team is that a higher-level suitability finding (Level 2) can be supported for Disqualifying Condition 2. This indicates the condition is not present, and new information is not likely to change this conclusion.

Disqualifying Condition 3. The consensus of the Core Team is that available information continues to support the lower-level suitability finding for this disqualifying condition (Level 1). Results of monitoring, coupled with interactions with the NPS regarding these results, will provide the basis for supporting a higher-level suitability finding for this condition. While uncertainties remain about the potential level of impact on down-gradient water resources, available evidence suggests that impacts will not be significant and that the DOE could mitigate any potentially significant impacts by using alternative water sources.

3.3.2.2 SOCIOECONOMIC IMPACTS TECHNICAL GUIDELINE

3.3.2.2.1 Statement and Discussion of the Qualifying and Disqualifying Conditions

Qualifying Condition [10 CFR 960.5-2-6(a)]: "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."

Disqualifying Condition [10 CFR 960.5-2-6(d)]: "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."

Discussion. The history of the development of this guideline is noteworthy because it indicates that "...adverse socioeconomic impacts on affected local economies can generally be mitigated..." and that "...since these potentially adverse conditions could be mitigated in many cases, they would not disqualify a site." The discussion of the qualifying condition indicates "...it will also ensure that the system guideline, whose objective is to protect the socioeconomic well-being of the population, will be met." The favorable and potentially adverse conditions focus on common socioeconomic factors, such as effects on community services and housing, availability of labor supply, beneficial and adverse effects on the economy, and effects on present or future economic development. Those statements suggest that the DOE believes that the qualifying condition and the favorable conditions can be met and that the potentially adverse conditions can be avoided with sufficient planning of site characterization and repository development activities, coordination with the State of Nevada and affected units of local government, and a comprehensive socioeconomic mitigation program.

According to 10 CFR Part 960, the disqualifying condition for this guideline was developed in response to an NRC request for additional disqualifying conditions that address specific factors listed in Section 112(a) of the Nuclear Waste Policy Act (NWPA, 1983). The disqualifying condition is concerned with potential effects on the rights of water users and proximity to water supplies. The discussion in 10 CFR Part 960 indicates that the disqualifying condition could have been included in the guideline for natural resources, but was added here because the DOE believes that the most serious effects of a significant degradation of major water sources would be socioeconomic effects. This concern is also covered in the Preclosure Hydrology Technical Guideline in Section 3.3.3.3.

3.3.2.2.2 Approach for Socioeconomic Impacts Evaluation

The evaluation of the qualifying condition will rely on development of a comprehensive understanding of the socioeconomic characteristics of the southern Nevada region. The qualifying condition requires that "significant adverse social and/or economic impacts...can be offset by reasonable mitigation or compensation..." and that the requirements specified in the System Guideline (10 CFR 960.5-1(a)(2)) can be met. The Background Information for 10 CFR Part 960 suggests that the Socioeconomic Impacts qualifying condition can be addressed when potential socioeconomic effects are identified, significant adverse impacts are evaluated, and judgments made that they can be avoided or mitigated. The term "reasonable mitigation or compensation" is not defined in the guidelines. It appears that the meaning of this term will be defined through a series of interactions between the DOE and the State of Nevada and affected local government jurisdictions as required by the qualifying condition.

Information necessary to address the Socioeconomic Impacts qualifying condition will be developed during the process of preparing a socioeconomic impact assessment for the potential repository. Typically the socioeconomic impact assessment for a project of this magnitude includes an evaluation of potential local and regional economic and demographic effects and the resulting changes in public infrastructure requirements, as well as the social effects that may occur both as a direct result of the project and as a result of the involvement of special interest groups. An evaluation of the potential effects that may result from public response to the controversial nature of the project and the public perception of the risks associated with the transportation and storage of high-level nuclear waste may also be necessary because the extent and duration of many economic, demographic, and social changes are related to public perception. The possibility that many of these potential social and economic effects could be long term and may extend beyond the operational life of a repository will need to be addressed in the final assessment of socioeconomic impacts.

The guideline indicates that the qualifying condition will be addressed through "...a process of analysis, planning, and consultation among the DOE, affected State and local government jurisdictions, and affected Indian tribes." The DOE has continued efforts to accomplish this coordination with affected parties by developing the Yucca Mountain Site Characterization Project Socioeconomic Plan (DOE, 1991e). This document, which was prepared in consultation with the State of Nevada and affected counties, specifies a process of consultation, communication, and coordination between the DOE and the affected parties to ensure that socioeconomic issues and concerns are identified, potential socioeconomic effects are evaluated, and appropriate impact mitigation strategies are developed and implemented. The process of interaction between the affected parties and the DOE requires coordination of their respective socioeconomic programs to avoid unnecessary duplication of efforts and is designed to be sufficiently flexible to respond to changes in social and economic issues associated with the project.

The guideline also requires that socioeconomic impacts "...induced in communities and surrounding regions by repository siting, construction, operation, closure, and decommissioning can be offset by reasonable mitigation or compensation..." The Nuclear Waste Policy Act (NWPA, 1983) requires the DOE to avoid or minimize adverse socioeconomic impacts to the maximum extent practicable and gives the DOE the authority to provide financial and technical assistance to mitigate unavoidable impacts. The Section 175 Report (DOE, 1988b) and the Socioeconomic Plan for the Yucca Mountain Site Characterization Project (DOE, 1991e) both indicate that the process of identifying socioeconomic impacts and developing appropriate mitigation strategies requires communication and cooperation between the DOE and the affected parties. While the strategies for mitigating population-related impacts on public services and facilities are relatively well known, methods for addressing potential social impacts and perception-based impacts are less clearly understood. The DOE will need to work with the affected parties to determine which socioeconomic effects are considered adverse impacts and how they can most efficiently be addressed with reasonable mitigation or compensation.

With regard to the evaluation of the disqualifying condition, the Core Team made the following assumptions: If significant and unmitigatable degradation of the quality or quantity of water in the area were expected as a result of development of a repository at Yucca Mountain, the disqualifying condition would be present and a conclusion that the site was unsuitable would be supported. The Core Team understands that the DOE has agreed to conduct a water resources monitoring program to develop criteria for quantifying potential impacts on area aquifers for the repository development phase of the program. Criteria will be based on water-level drawdowns in wells and reduction in spring outflow for water quantity and on Clean Water and Safe Drinking Water Act standards for water quality. According to current plans, the DOE will consult with the NPS regarding water resources in down-gradient areas of the site. A mutually agreed-upon monitoring program has been developed to identify potential significant adverse impacts and ensure protection of water resources.

3.3.2.2.3 Status of Current Socioeconomic Impacts Information

The evaluation presented in the Environmental Assessment (EA) (DOE, 1986) indicated that no significant adverse socioeconomic impacts are expected to occur as a result of siting a repository at Yucca Mountain. The qualifying condition requires only that the significant adverse impacts be mitigatable. The EA reported a Level 3 (lower-level) finding for the qualifying condition based on the information concerning the repository program that was available at that time.

Several socioeconomic studies have been completed and substantial additional information has been acquired since the development of the EA. These studies are ongoing and continue to refine the understanding of the area surrounding Yucca Mountain, as well as provide improved documentation of changes in regional socioeconomic characteristics. The DOE produced the Section 175 Report (DOE, 1988b) as required by the Amendment to the Nuclear Waste Policy Act of 1987 (NWPAA, 1987). This report provided a more detailed assessment of potential socioeconomic impacts in the region, but did not substantially change the conclusions reported in the EA.

The report indicated that impacts on community services and facilities (e.g., schools, health services, and transportation networks) may occur particularly in the small rural communities closest to Yucca Mountain. The schedule and resource requirements (e.g., labor and material requirements and cost estimates) for the repository program were also updated for use in preparation of the Section 175 report.

The DOE's ongoing socioeconomic monitoring program and the development of socioeconomic profiles for the region have also contributed to a better understanding of potential socioeconomic impacts. Because of the rapidly changing socioeconomic environment of the area, particularly in Clark County, and the need to develop a complete data base of information for use in preparation of an environmental impact statement, the DOE has already initiated many components of the socioeconomic program for the Yucca Mountain Site Characterization Project. The socioeconomic studies conducted by the DOE primarily have focused on the affected counties, Nye, Clark, and Lincoln, and on the State of Nevada as a whole (see Section 3.3.2.1.3.1 for a description of the program to address Native American concerns). As circumstances require, socioeconomic studies will be needed to examine other potentially affected areas, such as counties or communities that may experience socioeconomic effects related to potential rail and highway access routes to the Yucca Mountain site.

The State of Nevada and Nye, Clark, and Lincoln counties are currently conducting their own assessment of potential impacts with the goal of requesting financial and technical assistance from the DOE to mitigate those impacts. The State of Nevada has initiated a comprehensive socioeconomic assessment program, which includes evaluation of potential economic and demographic effects, as well as potential effects on public services and facilities. A major focus of the State's socioeconomic program is on potential sociocultural impacts and on potential perception-based impacts on tourism and economic development. While the complete results of these assessments are not yet available, the State of Nevada has produced reports regarding particular components of their program and an interim report (Mountain West Research, 1989) that summarizes the results of their entire socioeconomic program. In those reports the State of Nevada has indicated that population-related impacts on public infrastructure and fiscal capacity are expected. The reports also suggest that perception-based impacts on tourism and economic development are anticipated but the extent of those effects is not yet fully understood. All counties contiguous to Nye County are expected to be granted affected status and financial assistance for such activities as socioeconomic impact assessments. In addition to Nye, Clark, and Lincoln, the counties include White Pine, Eureka, Lander, Churchill, Mineral, and Esmeralda counties in Nevada and Inyo county in California.

With regard to the disqualifying condition, the EA discussed water resource information in the Yucca Mountain area both from quantity and quality standpoints. All information is still technically accurate; however, detailed water studies have not been undertaken at the site. There are extensive water study programs identified for the site characterization program, as well as for the environmental program. The site characterization program will attempt to characterize the regional hydrology and to answer questions associated with ground-water pathways and associated travel times. The environmental program is concerned with the specifics of this guideline; however, there is some overlap of information-gathering activities between site characterization and environmental programs.

The disqualifying condition addresses the question of significant and unmitigatable degradation of the quality or quantity of water suitable for residential or agricultural use. While additional information concerning water use and water availability has been developed since the preparation of the EA, the data base is not complete. The environmental water resources monitoring program for parameters related to quantity and quality has been designed (DOE, 1991c) and recently been initiated. It consists of approximately 40 monitoring locations for use in measuring water levels, spring outflow, and water-quality parameters. The monitoring program is not, however, specifically designed to address impacts associated with repository development, as the disqualifying condition states. The monitoring program is currently geared toward identifying potential impacts from site characterization activities. The data gathered from this program will certainly help in addressing the same types of issues during the remainder of the repository program.

3.3.2.2.4 Conclusions and Recommendations for Future Socioeconomic Impacts Activities

Disqualifying Condition. The EA reported a Level 1 (lower-level suitability) finding for the disqualifying condition and this finding continues to be supported by this evaluation. Additional information relevant to the condition has been developed and significant degradation of water quality or quantity that cannot be mitigated is not expected if a repository is developed at Yucca Mountain. However, the consensus of the Core Team is that insufficient data is currently available to support a Level 2 (higher-level) suitability finding.

Qualifying Condition. The consensus of the Core Team is that the socioeconomic information developed since the preparation of the EA continues to support the Level 3 (lower-level suitability) finding for the qualifying condition. Given the requirement to use the process of analysis, planning, and consultation with the affected parties that is prescribed in the guideline, the consensus of the Core Team is that information is not yet available to support a higher-level suitability finding for this condition. However, unmitigatable social and/or economic impacts are not expected to occur if a repository is developed at the Yucca Mountain site.

Discussion. Efforts are ongoing to improve the understanding of socioeconomic characteristics in southern Nevada. Support for the higher-level suitability finding for the qualifying condition will ultimately need to be based on (1) information concerning repository requirements (e.g., labor requirements, material requirements, and schedule); (2) comprehensive information concerning the socioeconomic characteristics of the region; (3) detailed projections of the socioeconomic effects of the repository; and (4) consultation with the State of Nevada and local government jurisdictions to evaluate their socioeconomic impact assessments and requests for mitigation.

Additional information concerning water quality and water availability in the area surrounding Yucca Mountain is believed to be necessary to support a higher-level suitability finding for the disqualifying condition. It is reasonable to assume that the environmental water resources monitoring program will be redirected in scope to include the repository phase of the program. This information should be evaluated together with forecasts of repository-related economic and demographic effects prepared to evaluate the qualifying condition.

3.3.2.3 TRANSPORTATION TECHNICAL GUIDELINE

3.3.2.3.1 Statement and Discussion of the Qualifying Condition

Qualifying Condition [10 CFR 960.5-2-7(a)]: "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."

Discussion. The qualifying condition for this guideline can be interpreted as requiring that rail and highway access routes be sited and constructed using existing technology in a manner that does not place unique demands on the transporter and transportation package. Rights-of-way are to be selected so that they do not pass through National Parks, Wilderness areas, Scenic River areas, or other areas where transportation of high-level waste would pose an unacceptable and unmitigatable environmental or public health impact.

Evaluation of transportation risks associated with the repository requires a national perspective, and two relevant DOE programs are currently underway. The first is being conducted by the DOE's Yucca Mountain Site Characterization Project and focuses on Nevada. The second is being conducted by the DOE's Office of Storage and Transportation and focuses on areas outside Nevada.

3.3.2.3.2 Approach for Transportation Evaluation

In evaluating this guideline, the term "local" is interpreted to mean within the State of Nevada. The approach for evaluating the qualifying condition includes the following steps:

1. Identify feasible rail and highway access routes
2. Evaluate the routes against criteria described in the qualifying condition of this guideline
3. If a feasible route is identified that meets the criteria in the qualifying condition with high confidence, then it can be concluded that available information supports a higher-level suitability finding.

3.3.2.3.3 Current Status of Findings for Transportation

This section summarizes the findings on the transportation guidelines from the Environmental Assessment (EA) (DOE, 1986), reviews information available since the EA, and provides a status of the findings that can be supported for this guideline.

3.3.2.3.3.1 Summary of Environmental Assessment Findings for Transportation

Evaluations of site highway access in the EA were based on upgrading an existing access route to the Nevada Test Site (NTS) in the vicinity of Amargosa Valley, constructing a new road along Fortymile Wash to provide a more direct route, constructing a combination highway and rail bridge across the Wash near an existing road, and then following the existing access route to the potential repository surface facility site. No issues were raised in the EA with regard to compliance with 10 CFR 960.5-2-7 on highway access.

Evaluations of site rail access in the EA were based on a route that originated at Dike Siding, about 11 miles northeast of Las Vegas, went around the south end of the Sheep Mountain Range, and then northwest along Route U.S. 95 north to Mercury. This route then enters the NTS and passes by Skull Mountain to the repository site across the combination highway and rail bridge proposed across Fortymile Wash. No serious issues were raised with this route in the EA. Subsequent work, however, has shown this route unfeasible because of land-use conflicts with wilderness study areas and residential development (DOE, 1990f).

Preliminary risk analyses of transportation were presented in the EA. Regional and national transportation risk levels for the 100-year life of the repository program from the movement of high-level waste (HLW) were estimated and are presented in the following table.

TRANSPORTATION RISKS

	Radiological Fatalities	Nonradiological Fatalities	Injuries
Regional	0.07 to 0.37	0.57 to 1.88	1.48 to 18.82
National	0.07 to 11.3	3.0 to 42	29.4 to 480

The levels of risk presented in this table are not judged significant, especially since they represent 100-year estimates. A commitment was made in the EA comment-response document to conduct route-specific evaluations of high-level waste transportation when a repository Environmental Impact Statement (EIS) is developed, as required by the Nuclear Waste Policy Act (NWPA, 1983).

3.3.2.3.3.2 Review of Information Obtained since Environmental Assessment for Transportation

Transportation activities since the EA have focused on additional feasibility evaluations for site access (DOE, 1990f; De Leuw, Cather & Company, 1991) and on the collection of route-specific data that will be used, with public review during scoping hearings, to support the preparation of an EIS for the repository according to the DOE (1990n).

Site access studies have shown three potentially feasible rail access routes from existing mainline railroad locations to the Yucca Mountain site and an alternate highway access from US Highway 95 (DOE, 1990f). These routes are being studied in more detail (De Leuw, Cather & Company, 1991). Site access routes are being sought that will conform to national standards for construction and operation. The rail access study for the Caliente route (De Leuw, Cather & Company, 1991) indicates that for the conceptual design of that alignment, including several options, the railroad can be constructed within the limitations of present railroad engineering practices and normal operating standards. Additional studies will be needed to identify alignments that have similar characteristics. The highway access can also be constructed within present highway engineering practices and does not traverse federally protected lands. Windshield surveys of the potential routes and a review of maps and land use have not identified any features that would place unique demands on the cask or transporter or the construction of accesses to the site.

Truck routes over existing roads in Nevada identified in the EA are no longer being considered by the DOE. This includes route US 93 over Hoover Dam. Regulations promulgated by the U.S. Department of Transportation require that HLW shipments follow either the quickest interstate highway route or a state-designated alternative. Since the EA, DOE evaluations of routes in Nevada have identified Interstate 15 and US Highway 95 from Las Vegas to Amargosa Valley as the only allowable route at this time (DOE, 1989b). Alternative routes for large-quantity shipments of radioactive materials by truck are currently being evaluated by the State of Nevada (Ardila-Coulsen, 1989).

Transportation of spent fuel in Nevada will not require transportation system components to meet performance standards more stringent than those specified in the applicable Department of Transportation (DOT) and Nuclear Regulatory Commission (NRC) regulations. Transportation system components consist of the transporter components (truck or train) and the packaging components (cask, impact limiters, and personnel shield). The DOT performance standards that apply to the shipment of spent fuel and high-level waste are in 49 CFR 173.401-476, 49 CFR Part 174 and 49 CFR Part 177. These regulations apply throughout the United States. The NRC performance standards that apply to the packaging components are in 10 CFR Part 71 and 10 CFR Part 73. These regulations also apply to shipments of spent fuel and high-level waste throughout the United States. Therefore, siting the repository in Nevada would not require more stringent performance standards for the transportation system components.

Collection of transportation data for eventual use in an EIS is a broad effort that includes the DOE-Yucca Mountain Site Characterization Project

Office program (DOE, 1990e), the DOE national program, the State of Nevada under DOE funding provided for oversight, University of Nevada at Reno under a cooperative agreement with the DOE, and efforts by county and city governments with funds provided under grants for impact evaluations. Results of these efforts to date have focused on understanding transportation systems and models rather than risk analysis, but no data has been collected that imply the high-level waste would pose risks any greater than those predicted in the EA to either Nevada or the rest of the nation. Changing the routes from those in the EA would likely lower the risk to Nevadans because alternative routes would pass through less populated areas of the state. Access routes currently being evaluated will bypass cities and towns except in situations where a local community desires that the rail spur be located close to or in the community for economic development purposes.

Evidence suggests that spent nuclear fuel has been shipped throughout the United States and worldwide safely for over 30 years. Available technology appears to provide the required protection to the public and the environment, while at the same time, allows efficient, dependable, cost-effective operation.

3.3.2.3.3.3 Status of Current Information for Transportation

While most Nevada routes in the EA have been changed, more information is available on current routes relative to the qualifying condition for this guideline. The consensus of the Core Team is that support for the lower-level suitability finding (Level 3) for the qualifying condition has been strengthened since the EA. Potentially feasible routes have been identified for both highway and rail access. Evaluations of the routes are proceeding, and preliminary results indicate that the routes could meet applicable standards. As was the case with the qualifying conditions for the Environmental Quality and Socioeconomic Impacts Guidelines, support for a higher-level finding on this qualifying condition is judged to require further understanding of the potential risks to the public and impacts on the environment because of the transport of radioactive wastes, and the identification of mitigation measures to avoid unacceptable impacts. Issues that are likely to require resolution before such a finding could be made include the following:

Land Access

Rights-of-way for highway and rail access are not currently under DOE control. There is a potential need for Federal condemnation proceedings for private holdings and access to mining claims areas if negotiations under DOE Order 4300.1B (DOE, 1987a) with the owners or claimants cannot be satisfactorily concluded. Contacts would need to be made with holders of titles and claims before finalizing any impact assessments. Most lands along potentially feasible routes are currently under Federal control.

Transportation Planning

A number of planning issues related to transportation operations remain open at this time (DOE, 1991b). These issues include the following:

- Routing
- Emergency response
- Carrier availability
- Cask designs
- Interface between a Monitored Retrievable Storage Facility and the Repository
- Safeguards & security
- Access Route Operational Plans (De Leuw, Cather & Company, 1991).

Access Route Characterization

The previous routing study (De Leuw, Cather & Company, 1991) provides a conceptual design for an alignment that does not traverse federally protected lands. Alternatives to the current Caliente route need to be developed that have similar characteristics. This will allow flexibility in the evaluation of impacts.

Public Involvement

It could be beneficial for the current dialog with members of the public at locations along the Caliente route to be expanded to include communities on other routes and across the U.S. Recent actions by the DOE to expand the number of affected counties (see Section 3.3.2.2.3) in order for them to participate in transportation planning activities is a start toward this goal. Discussions with regional groups interested in transportation of high-level waste are ongoing under the Office of Storage and Transportation Systems.

3.3.2.3.4 Conclusions and Recommendations for Future Activities

Qualifying Condition. The consensus of the Core Team is that support for the lower-level suitability finding (Level 3) has been strengthened since the EA. The team believes that available information indicates that adverse transportation-related impacts to the public or the environment will not be significant or can be mitigated to acceptable levels. Additional information is needed, however, to reach the confidence needed to support a higher-level (Level 4) suitability finding for this condition.

Discussion

To provide support for a higher-level suitability finding (Level 4) on this guideline, the following actions are recommended:

1. Identify potential transportation-related impacts and mitigation strategies

2. Reduce uncertainty about issues identified in Section 3.3.2.3.3.3.

3.3.2.4 EVALUATION OF THE SYSTEM GUIDELINE FOR ENVIRONMENTAL QUALITY, SOCIOECONOMIC IMPACTS, AND TRANSPORTATION

3.3.2.4.1 Statement and Discussion of the Qualifying Condition

Qualifying Condition [10 CFR 960.5-1(a)(2)]: "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."

Discussion. This System Guideline defines the requirements that apply to the environment, socioeconomic, and transportation considerations that need to be addressed with regard to the potential siting of a repository at Yucca Mountain. The statement in the System Guideline regarding "hazards posed by the disposal of radioactive waste" does not apply merely to the potential radiation hazards from the waste, but also applies to all potential hazards to flora, fauna, and other areas from the siting activities.

3.3.2.4.2 Approach for Evaluation for the System Guideline for Environmental Quality, Socioeconomic Impacts, and Transportation

The technical basis for supporting a higher-level suitability finding on this System Guideline will be developed through evaluations of the associated group of technical guidelines. High confidence will be needed that potentially significant environmental, socioeconomic, and transportation-related impacts can be mitigated through the use of acceptable measures. By avoiding adverse impacts or mitigating them to acceptable levels, the public and the environment should be adequately protected from the potential hazards posed by waste disposal, as required in the qualifying condition.

3.3.2.4.3 Status of Current Information for System Guideline for Environmental Quality, Socioeconomic Impacts, and Transportation

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

The details of the above information, as presented in the appropriate environmental technical sections of the EA, led to the conclusion that the existing information did not support the finding that the site was not likely to meet the qualifying condition (Level 3). Supporting this lower-level suitability finding, the EA presented the position that there are no significant environmental impacts that cannot be mitigated; the socioeconomic welfare of the public can be preserved; transport of wastes can be conducted in compliance with regulations; and the public and the environment will be adequately protected from the hazards posed by radioactive waste disposal.

Data collection in the disciplines of environmental quality, socioeconomic impacts, and transportation has been ongoing since the EA to compile information on background conditions for subsequent impact assessments of site characterization activities. Those information updates are discussed under the appropriate technical guidelines in previous sections.

3.3.2.4.4 Conclusions and Recommendations for System Guideline for Environmental Quality, Socioeconomic Impacts, and Transportation

The consensus of the Core Team is that there is no reason to believe the Yucca Mountain site is not suitable with respect to the Environmental Quality, Socioeconomic Impacts, and Transportation Guidelines. Existing information continues to support the lower-level suitability findings (Level 3) for the System Guideline qualifying condition. This conclusion, previously reported in the EA, appears strengthened as a result of data that has been collected since the EA. However, uncertainties about the range of potential environmental, socioeconomic, and transportation-related impacts and the mitigation measures that may be needed to avoid significant impacts, do not allow a higher-level suitability finding for this System Guideline and most of its Technical Guidelines to be supported at this time. Further identification of potential impacts and concerns, collection of data to determine the significance of potential impacts, and development of acceptable mitigation and compensation strategies will provide the confidence needed to support higher-level suitability findings in the future.

3.3.3 EVALUATION OF GUIDELINES FOR EASE AND COST OF SITING, CONSTRUCTION, OPERATION, AND CLOSURE

The Preclosure Guidelines govern the siting considerations that deal with the operation of the repository before it is closed. The Preclosure Ease and Cost Guidelines do not relate directly to the health, safety, or welfare of the public or the quality of the environment, and consequently are ranked lower in importance according to 10 CFR 960.3-1-6 than the other preclosure guideline groups related more directly to these concerns. Even so, these guidelines are important because they are related to (1) the site characteristics that affect siting, construction, operation, and closure; (2) the engineering, materials, and services necessary to conduct these activities; and, indirectly, (3) the health and safety of repository personnel at the site.

The broad requirements that apply to the preclosure ease and cost considerations are stated in the Preclosure System Guideline qualifying condition:

> "Repository siting, construction, operation, and closure shall be demonstrated to be technically feasible on the basis of reasonably available technology and the associated costs shall be demonstrated to be reasonable relative to other available and comparable siting options." [10 CFR 960.5-1(a)(3)]

These requirements are not imposed by groups or agencies outside the DOE and are not subject to the licensing process. DOE imposed them on itself to ensure that the plans for siting (including site characterization), construction, operation, and closure are reasonable and take into account the availability of technology. The Technical Guidelines associated with this System Guideline are used to identify detailed geologic considerations important for meeting the broad requirements of the System Guideline. These considerations fall into the technical categories of surface characteristics (e.g., topography and terrain), rock characteristics (e.g., those related to the maintenance of openings or safety of workers), hydrology (e.g., potential for flooding or effects of ground-water conditions on construction), and tectonics (e.g., seismic hazards for surface facilities).

Evaluation of the Yucca Mountain site against the Ease and Cost Guidelines includes three elements: (1) evaluation of the disqualifying conditions of the technical guidelines; (2) system assessments to identify the issues affecting the general requirements of the system guidelines; and (3) evaluation of the qualifying conditions of the system and technical guidelines. The disqualifying conditions identify specific features or conditions that must be evaluated at the site. These conditions are evaluated according to the approach described in Section 1.2.4.

The system assessments for these guidelines identify issues associated with reasonably available technology (RAT) for siting, construction, operation, or closure of the repository system. Then the evaluation of the qualifying conditions focuses on whether any special measures will be needed to ensure that personnel will be safe and that applicable regulations can be satisfied. There are no standards that define RAT or that specify when special measures are required. The evaluation of the qualifying conditions therefore focuses on whether the associated conditions are met by considering factors such as the following:

- Special characteristics of the site and requirements of the repository system

- Technology proven in related projects (e.g., reactor facilities and spent-fuel handling facilities)

- Required personnel (e.g., availability of experienced and trained personnel)

- Time needed to implement any special measures

- Expected developments in construction technology in the foreseeable future

- Ability to complete prerequisites (e.g., permits and completion of start-up tests)

- Conflicts with other aspects of siting, construction, operation, or closure.

Costs of technologies needed for siting, construction, operation, or closure relative to those for other siting options were not explicitly considered in this evaluation. The Nuclear Waste Policy Amendments Act of 1987 effectively removed the requirement to consider such comparisons in determining whether the Yucca Mountain site should be recommended for repository development (NWPAA, 1987). The Core Team did not identify any characteristics of this particular site that would lead to use of mitigation techniques that are unusually expensive. Detailed considerations of costs, however, were not made in this evaluation.

A related concern is the type of suitability findings that can be supported if design requirements and plans for activities are not well developed. The Core Team assumed for this evaluation that as long as there are no fundamental constraints imposed by the characteristics of the site on design requirements, completed designs and plans are not necessary to draw conclusions regarding the ease and cost of design. Thus, the team decided it was possible to determine the suitability of the site with regard to ease and cost of preclosure activities even if design requirements and plans for activities were not completely developed.

Sections 3.3.3.1 through 3.3.3.4 provide the evaluations for each of the technical guidelines. Section 3.3.3.5 provides the evaluation of the system guideline for Ease and Cost of Siting, Construction, Operation, and Closure.

3.3.3.1 SURFACE CHARACTERISTICS TECHNICAL GUIDELINE

3.3.3.1.1 Statement and Discussion of the Qualifying Condition

Qualifying Condition [10 CFR 960.5-2-8(a)]: "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."

Discussion. No disqualifying condition is specified for this guideline, other than an inability to meet the qualifying condition. The intended scope of this guideline is indicated by the favorable conditions, which specify generally flat and well drained terrain, and the potentially adverse condition, which addresses surface characteristics and existing or planned impoundments of water that could cause failure of the engineered components of the repository.

The Preclosure Hydrology Technical Guideline, Section 3.3.3.3 of this evaluation, addresses hydrologic hazards pertaining to the underground components and portals for access to the underground. Therefore, this evaluation of surface characteristics addresses principally (1) the topography of the site relative to options for siting surface facilities important to safety, considering the ease of construction, and (2) mitigating flooding hazards.

3.3.3.1.2 Approach for Surface Characteristics Evaluation

3.3.3.1.2.1 Identification and Basis for Surface Characteristics Technical Issues

The technical issues for this guideline are derived from the qualifying condition and the favorable and potentially adverse conditions:

- Technical Issue 1: Flat and Well Drained Terrain

  Are areas that are sufficiently flat but well drained available to accommodate operational facilities with the use of reasonably available technology (RAT)?

- Technical Issue 2: Flood Protection

  Are areas that would not require engineered protection against flooding and erosion beyond that of RAT sufficiently available at the site?

3.3.3.1.2.2 Information Required to Resolve Surface Characteristics Issues

The approach for evaluating this guideline consists of acquiring and analyzing data on topography, geomorphology, meteorology, and the surface-water system, including flooding characteristics. Analysis of flooding characteristics relies on additional analyses to estimate the probabilities of flooding events within the operational lifetime of the repository, including a period for the retrieval of emplaced waste should it become necessary. A period of 100 years is assumed to represent the preclosure period.

Topographic maps, aerial photographs, field inspection, and the meteorological characteristics of the region provide the basic set of required information. Geomorphic data relevant to the evaluation include evidence of slope instability, extreme flood stages, and erosion. Flooding evaluation requires, first, the prediction of discharge along drainage channels from meteorological data and physical characteristics of the drainage basins, and second the translation of these discharges into inundation areas along the watercourses. In arid regions, runoff from infrequent, but intense storms commonly contains large amounts of sediment and other debris. Therefore, for such regions of predicted inundation areas need to be adjusted, and the consequences of debris loads should be considered.

Engineering analyses within current or modified repository-operations layouts and structural designs must then be performed to ensure that RAT is sufficient to serve as a basis for design.

3.3.3.1.3 Status of Current Surface Characteristics Information

3.3.3.1.3.1 Summary of Environmental Assessment Findings for Surface Characteristics

In the Yucca Mountain Environment Assessment (EA), the DOE (1986) concluded that available evidence does not support the finding that the site is not likely to meet the qualifying condition (Level 3). Further explanation of the basis for this and for determinations as to the existence of the favorable and potentially adverse conditions are given in Table 3-1.

The conclusions in the EA were based on 1:24,000-scale topographic maps with a 20-ft contour interval, field inspections, a flooding analysis by Squires and Young (1984), and preliminary designs of the repository-facility layout.

The conclusions for both the qualifying condition and the potentially adverse condition emphasize sheet flow during extreme storms as a characteristic that should be recognized, but RAT was considered adequate to mitigate this.

3.3.3.1.3.2 Information for Surface Characteristics Acquired since the Environmental Assessment

Topographic maps with 2-m contours (Wu, 1985) are now available for parts of the site area, and more detailed mapping is in progress. More detailed maps are needed for engineering design, but the maps available for the EA analysis are adequate for the purpose of this guideline evaluation.

Table 3-1. Summary of Environmental Assessment Findings for Surface Characteristics (DOE, 1986)

Condition	DOE Finding
FAVORABLE CONDITIONS	
1. Generally flat terrain.	The evidence indicates that this favorable condition is present at Yucca Mountain: surface facilities and access routes will be located in areas with generally flat terrain.
2. Generally well drained terrain.	The evidence indicates that this favorable condition is present at Yucca Mountain: there is a well-established drainage system; porous alluvial soils are present and the water table is deep; the area will not pond water.
POTENTIALLY ADVERSE CONDITION	
Surface characteristics that could lead to flooding of surface or underground facilities by the occupancy and modification of floodplains, the failure of existing or planned man-made surface-water impoundments, or the failure of engineered components of the repository.	The evidence indicates that this potentially adverse condition is present at Yucca Mountain: arroyo drainage system is subject to short periods of localized flooding during rare extreme storms; potential exists for minor flooding due to sheet flow during infrequent extreme storms, although standard drainage control measures are considered adequate to protect surface and underground facilities.
QUALIFYING CONDITION	
The site shall be located such that, considering the surface characteristics and conditions of the site and surrounding area, including surface-water systems and the terrain, the requirements specified in Section 960.5-1(a)(3) can be met during repository construction, operation, and closure.	Available evidence does not support the finding that the site is not likely to meet the qualifying condition (Level 3): surface facilities would be located on the flat eastern slopes of Yucca Mountain; areas are well drained but subject to short periods of localized sheet flow during rare extreme storms.

Although no studies have been directed specifically at slope stability in the preclosure period, general geomorphic inspection of the site area and studies of the Quaternary record (Whitney and Harrington, 1988, and in preparation) indicate stability of very steep slopes at the site for hundreds of thousands of years. Repository facilities would be sited on much gentler terrain.

A U.S. Bureau of Reclamation Probable Maximum Flood (PMF) study (Bullard, 1986) defines clear-water discharges, based on ANSI/ANS (1981) procedures considering Probable Maximum Precipitation for both general storms and local storms, which produce the greatest flows. Conversion of these discharges to inundation areas is in process. The discharges predicted by the PMF method are approximately twice those determined by Squires and Young (1984), reflecting the effect of applying a standard developed for use in the humid, eastern United States to the semiarid and arid southwest. Although the application of the ANSI/ANS standard to the Yucca Mountain site is highly conservative, a doubling of discharge over that of Squires and Young (1984) will not strongly expand inundation areas. Bullard (1986) also notes that there are no known examples of flood peaks that have exceeded expected results from predicted PMF flow rates.

3.3.3.1.4 Conclusions and Recommendations for Surface Characteristics Future Activities

The consensus of the Core Team was that the Yucca Mountain site is qualified under the conditions of the Surface Characteristics Technical Guideline and that it is highly unlikely that future site or design information would identify requirements for measures that are beyond RAT. This conclusion is based on the judgment that positions taken in the EA not only are confirmed by subsequent information, but also are strengthened by additional slope-stability and PMF studies.

No site-characterization activities are required for evaluating the Yucca Mountain site against this technical guideline. More detailed topographic information, however, is needed for design purposes, as are more refined definitions of PMF inundation areas and of the required engineered structures to ensure adequate protection from sheet flow, debris-laden flooding, and lateral erosion of channels. Additionally, characterization of debris transport and deposition should continue because of its importance in understanding the effects of Quaternary climates in the site area; the results will also benefit facility-siting decisions.

3.3.3.2 ROCK CHARACTERISTICS TECHNICAL GUIDELINE

3.3.3.2.1 Statement and Discussion of the Qualifying and Disqualifying Conditions

Qualifying Condition [10 CFR 960.5-2-9(a)]: "The site shall be located such that (1) the thickness and lateral extent and the characteristics and composition of 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 in §960.5-1(a)(3) can be met."

Disqualifying Condition [10 CFR 960.5-2-9(d)]: "The site shall be disqualified if the rock characteristics are such that the activities associated with 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."

Discussion. The Preclosure Rock Characteristics Guideline occurs in a category of guidelines addressed to the "Ease and Cost of Siting, Construction, and Closure." In the Environmental Assessment (EA), the Preclosure Rock Characteristics Guideline was interpreted as ensuring "...that due consideration is given to...(1) the ease and cost of repository siting, construction, operation, and closure, and (2) the safety of repository workers." In addition to the qualifying and disqualifying conditions, this guideline contains two favorable and five potentially adverse conditions, which are discussed in Section 3.3.3.2.3.1.

3.3.3.2.2 Approach for Preclosure Rock Characteristics Evaluation

3.3.3.2.2.1 Identification and Basis for Preclosure Rock Characteristics Technical Issues

- Technical Issue 1: Host Rock Thickness and Lateral Extent

  What lateral extent and thickness is required for the potential repository host rock, and does the Yucca Mountain site meet this requirement?

Alternate methods of construction for the potential repository are being considered; different features of the repository than those assumed in the EA and Site Characterization Plan (SCP) have been proposed. These proposals, if adopted, may change the thermal loading, waste emplacement layout, and size of the underground facilities of the potential repository. Decisions to use methods of construction for the repository or to omit or include features in the repository different from those assumed in preparing the EA and SCP may have to be supported by additional rock characteristics data and design analyses. For example, the use of tunnel boring machines with a large-turning-radius for underground excavation and any requirement for reduced thermal loadings (concepts favored by some critics of the repository conceptual design) will necessitate a revision in the repository design bases.

- Technical Issue 2: Personnel Safety

  Are the host and surrounding rock mass properties adequate to ensure the safety of personnel during planned preclosure operating activities? Are the properties adequate to permit using RAT to perform these activities and to control the repository operations environment?

The characteristics and behavior of the rock mass surrounding the underground operations area are important considerations regarding preclosure operating activities. Rock that weakens or disintegrates as a result of heating or changes in the stress field due to excavation is undesirable and may pose a threat to the safety of repository workers or preclude performance of preclosure activities (e.g., waste retrieval) using RAT.

- Technical Issue 3: Inhalation Hazards

  Are inhalation hazards that cannot be mitigated by RAT likely to be encountered during repository siting, construction, operation, and closure activities?

Underground operations involve potential risks, including the inhalation of hazardous materials aerosolized during mining, operations, or accidents. The question associated with this issue is whether identified risks can be mitigated by RAT, so as not to cause undue hazard to personnel.

3.3.3.2.2.2 Information Required to Resolve Preclosure Rock Characteristics Issues

Decisions in favor of lower thermal loadings, which could increase the thickness or lateral extent requirements for the underground facilities, may require additional site characterization to determine the properties of areas outside the primary repository area. Other investigations of site-specific rock properties and behavior will improve confidence of current host-rock properties. The human biological activity of mordenite also needs to be investigated to establish if it could represent an inhalation hazard. Section 3.3.3.2.3.2 provides additional information about the basis for this concern.

3.3.3.2.3 Status of Current Preclosure Rock Characteristics Information

3.3.3.2.3.1 Summary of Environmental Assessment Findings for Preclosure Rock Characteristics

The thickness of the host rock was estimated on the basis of analyses of borehole samples while its lateral extent was estimated using these analyses and observations from surface reconnaissance. Comparing these estimates to the size of the underground facilities as described in the preliminary design of the potential repository, the EA authors concluded that the thickness of the preferred part of the densely welded devitrified portion of the Topopah Spring Member, while variable, was everywhere adequate. The lateral extent of the host rock was also adequate, but did not offer much flexibility, according to the EA authors.

Findings regarding the qualifying and disqualifying conditions were made almost exclusively in terms of the geoengineering properties of the host rock and the use of construction methods similar to those used in tunnel activities at the Nevada Test Site (NTS). Other concerns addressed included brief reference to mitigating the thermal effects of waste emplacement and dust and radon hazards through ventilation design.

To decide whether undue hazard or significant risk was occasioned by construction, operation, and closure activities, it was assumed in the EA that hard-rock metal mining was analogous to the tunnel activities at the NTS. Furthermore, these activities associated with a repository situated at Yucca Mountain were assumed to be similar to the NTS tunnel activities. On the basis of these analogies, the EA concluded that the site was not disqualified and that it is likely to meet the qualifying condition. The analogy between NTS and repository activities was based upon the further assumption that the geomechanical characteristics of the formations in which the operations occur at the NTS were similar to those planned for repository operations at Yucca Mountain.

The EA concluded that repository siting, construction, operation, and closure was technically feasible on the basis of RAT. Reasonable cost was not addressed absolutely or relatively. A synopsis of the EA findings regarding the qualifying, favorable, and potentially adverse conditions is provided as Table 3-2.

3.3.3.2.3.2 Information on Preclosure Rock Characteristics Acquired Since the Environmental Assessment

The limitations on surface-disturbing work at the Yucca Mountain site have largely precluded the acquisition of new data to affirm or refute the EA findings regarding thickness, lateral extent, characteristics, and composition of the host rock. Improved analyses of existing borehole samples, however, have largely affirmed earlier conclusions regarding host rock thickness and lateral extent: the primary repository area has approximately 1850 potentially usable acres. The repository design has continued to evolve; a conceptual design report was completed in support of the SCP (SNL, 1987). The underground area requirement used as the design basis in that document was 1,420 acres, or 100 acres less than that assumed by the EA authors. Emplacement strategies may affect the areal space requirement for the underground facilities. Elements of these strategies include waste package orientation, areal thermal loading, and inventory management method. Several of these elements have been the subject of recent reports; decisions on reference concepts for design bases have not been made.

It is possible that the injury incidence frequencies previously used to argue that no undue hazard or significant risk would be occasioned by construction, operation, and closure activities may not have included latent health effects that could be associated with inhalation hazards. Recent epidemiological studies prompted by an inordinate frequency of mesothelioma

Table 3-2. Summary of Environmental Assessment Findings for Preclosure Rock Characteristics (DOE, 1986)

Condition	DOE Finding
QUALIFYING CONDITION	
The site shall be located such that (1) the thickness and lateral extent and characteristics and composition of the host rock will be suitable for accommodation of the underground facility; (2) repository construction, operation, and closure will not cause undue hazard to personnel; and (3) the requirements specified Section 960.5-1(a)(3) can be met.	Available evidence does not support the finding that the site is not likely to meet the qualifying condition (Level 3): thickness and lateral extent of host rock is expected to provide adequate, but not significant, flexibility for the lateral layout and reasonable flexibility for vertical repository positioning; no rock in characteristics that could cause undue hazards to personnel have been identified or are expected to be encountered.
FAVORABLE CONDITIONS	
1. A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and of the underground facility.	The evidence indicates that this favorable condition is present at Yucca Mountain: significant lateral flexibility cannot be claimed until site characterization data are available.
2. A host rock with characteristics that would require minimal or no artificial support for underground openings to ensure safe repository construction, operation, and closure.	The evidence indicates that this favorable condition is present at Yucca Mountain: minimal artificial means are required to support similar tuffs at the NTS; a similar approach should ensure safe repository construction, operation, and closure.
POTENTIALLY ADVERSE CONDITIONS	
1. A host rock that is suitable for repository construction, operation, and closure, but is so thin and laterally restricted that little flexibility is available for selecting the depth, configuration, or location of an underground facility.	The evidence indicates that this potentially adverse condition is present at Yucca Mountain: significant lateral flexibility cannot be claimed.

Table 3-2. Summary of Environmental Assessment Findings for Preclosure Rock Characteristics (DOE, 1986) (continued)

Condition	DOE Finding
2. In situ characteristics and conditions that could require engineering measures beyond reasonably available technology in the construction of the shafts and underground facility.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: shafts and underground facility can be constructed using proven, standard methods.
3. Geomechanical properties that could necessitate extensive maintenance of the openings during repository operation and closure.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: conventional rock bolts and wire mesh are expected to provide adequate support and require minimal maintenance.
4. Potential for such phenomena as thermally induced fracturing, the hydration and dehydration of mineral components, or other physical, chemical, or radiation-related phenomena that could lead to safety hazards or difficulty in retrieval during repository operation.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: welded tuff is expected to have sufficient physical and chemical stability to ensure safety and retrievability; no potentially hazardous physical, chemical, or radiation-related phenomena have been identified.
5. Existing faults, shear zones, pressurized brine pockets, dissolution effects, or other stratigraphic or structural features that could compromise the safety of repository personnel because of water inflow or construction problems.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: an unsaturated zone repository is not expected to have water in flow, and stratigraphic and structural features are not expected to compromise safety.

in the population of the Cappodocian region of Turkey have implicated the fibrous zeolite mineral, erionite (Baris et al., 1987). Erionite's marked biological activity has been confirmed by laboratory studies (Wagner et al., 1985). Erionite has been identified as a fracture-lining mineral in drill hole UE-25a #1 in the basal vitrophyre of the Topopah Spring Member (Bish and Vaniman, 1985; Bish and Chipera, 1986). This very localized occurrence, possibly restricted to fractures, should pose little or no health hazard to workers or to the public. The unit that directly underlies the potential host rock, the Calico Hills unit, contains significant amounts of mordenite, which has morphologic, mineralogic, and chemical similarities to erionite. Limited toxicological studies on mordenite suggest that this mineral is fibrogenic but not carcinogenic. The samples used in these studies were poorly characterized, however, and substantial uncertainty remains regarding the biological activity of this mineral. The Calico Hills unit is likely to represent a major natural repository barrier during the postclosure timeframe, and adequate characterization of this unit is currently expected to involve extensive drifting. Therefore, the potential for an inhalation hazard to workers and an environmental impact from mining in this formation must be evaluated. Uncertainty remains concerning the occupational health risk and environmental impact represented by mordenite. However, reasonably available ventilation and health protection technology is likely to be adequate to mitigate the hazard.

3.3.3.2.4 Current Status of Preclosure Rock Characteristics Technical Issues

- Technical Issue 1: Host Rock Thickness and Lateral Extent

  Until firm decisions are made about the design bases and requirements for the repository, the thickness and lateral extent of host rock that will provide adequate contingency are uncertain. In addition, relatively limited information about rock properties within and outside the primary repository area increases the uncertainty related to this issue. This issue thus remains unresolved.

- Technical Issue 2: Personnel Safety

  Personnel are unlikely to be subjected to undue hazards or significant risks due to unsafe conditions during construction and operation in the underground facility. World-wide experience in materials with similar rock properties suggests that conventional underground support technology will be adequate to ensure worker safety. In addition, repository operating temperatures are subject to control through design using reasonable available technology.

- Technical Issue 3: Inhalation Hazards

  Although specific hazards related to mordenite, a mineral present in the Calico Hills unit, have not been investigated, it is likely that ventilation and health-protection technology is adequate to mitigate any hazards identified.

3.3.3.2.5 Conclusions and Recommendations for Future Preclosure Rock Characteristics Activities

Qualifying Condition: The consensus of the Core Team is that a lower-level suitability finding (Level 3) continues to be supported for the qualifying condition for Preclosure Rock Characteristics. However, new information to be acquired regarding the design of the underground facilities and thermomechanical and thermal properties of the host and surrounding rocks could change this conclusion.

Disqualifying Condition: The consensus of the Core Team is that the disqualifying condition for Preclosure Rock Characteristics is not present at the Yucca Mountain site. Further, on the basis of the expectation that rock characteristics will not pose significant risks to the health and safety of repository workers, new information is considered to be unlikely to change this conclusion. Confidence is thus sufficient to support a higher-level suitability finding (Level 2) for this condition.

Discussion. Additional information needed to support a higher-level suitability finding on the qualifying condition for this guideline will be gained from the following activities:

- Development of a more mature repository design concept, especially with regard to the local and overall thermal loading constraints. This activity may include technical factors, such as determining the characteristics of the rock in potential expansion regions outside the primary repository area, as well as policy issues, such as establishing the design capacity of the repository

- Acquisition of additional site-specific data related to rock characteristics, including thermal transport and thermomechanical properties and fracture frequency, orientation, and dimensions.

Although the consensus reported above is that a higher-level finding can be supported for the disqualifying condition, additional information will provide further confidence in this conclusion. Studies of the human biological activity of mordenite and an analysis of RAT alternatives to mitigate any occupational inhalation hazard or environmental impacts attributable to mordenite mining will provide enhanced confidence. An alternative approach to characterizing the Calico Hills that obviates this hazard and potential impact could also provide improved confidence.

3.3.3.3 HYDROLOGY TECHNICAL GUIDELINE

3.3.3.3.1 Statement and Discussion of Qualifying and Disqualifying Conditions

Qualifying Condition [10 CFR 960.5-2-10(a)]: "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."

Disqualifying Condition [10 CFR 960.5-2-10(d)]: "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."

Discussion. This technical guideline is concerned with the following: (1) the potential effects of ground water on the construction and sealing of shafts, ramps, and other underground openings, including the repository itself; (2) the potential for flooding of underground facilities by surface water; and (3) the availability of water for repository construction and operation. The objectives of the guideline are to ensure that the geohydrologic setting will (1) be compatible with repository construction, operation, and closure and (2) not compromise the functions of shaft liners and seals. The qualifying condition refers to the "Ease and Cost of Siting, Construction, Operation and Closure" portion of the Preclosure System Guideline (960.5-1(a)3), namely, "Repository siting, construction, operation, and closure shall be demonstrated to be technically feasible on the basis of reasonably available technology (RAT), and the costs shall be demonstrated to be reasonable relative to other available and comparable siting options." The Nuclear Waste Policy Amendments Act of 1987 identified the Yucca Mountain site as the only site to be characterized (NWPAA, 1987). As a consequence, comparative evaluation of costs among candidate sites is not possible.

According to the background information presented in Part I of 10 CFR 960, the disqualifying condition was originally added to this technical guideline in response to U.S. Nuclear Regulatory Commission (NRC) comments. The qualifying and disqualifying conditions are therefore quite similar in that they both refer to the use of RAT (the qualifying condition through the connection to the System Guideline). Both conditions invoke hydrologic threats to construction, operation, and closure. However, the qualifying condition specifically identifies the functions of the shaft liners and seals as crucial for repository construction, operation, and closure and the disqualifying condition further ties exploratory shaft construction to repository development.

This guideline consists of three favorable conditions and one potentially adverse condition that were evaluated in the Environmental Assessment (EA), discussed in Section 3.3.3.3.3.1. Evidence to date indicates that the potentially adverse condition dealing with the presence of ground water conditions that require measures beyond standard engineering measures and RAT are not present at the Yucca Mountain site. Yucca Mountain also appears to satisfy all the favorable conditions, with the possible exception of the infrequent presence of surface water (flash floods and sheet flow) from rare but extreme storms. The EA presented lower-level findings for both the qualifying and disqualifying conditions, indicating that available evidence supported nomination of the site as suitable for characterization.

A semantic problem arises in interpreting this guideline. The qualifying condition states that the geohydrologic setting of the site will be "compatible" with those activities required for "repository construction, operation, and closure." The word "compatible" can have legal or jurisdictional connotations. If Yucca Mountain is selected for repository development, a reservation of water rights will be necessary. The basic technical issue of adequacy of water to perform the preclosure activities is therefore complicated by possible water withdrawal or water rights issues.

An additional semantic issue concerns the use of the word "shafts" in both the qualifying and disqualifying conditions when the primary access to the underground facility may actually employ ramps. Recent studies have been conducted to evaluate alternative configurations and layouts for the underground site characterization facility (Dennis, 1991; Stevens and Costin, 1991). These studies indicate that ramps are under consideration to be part of the Exploratory Studies Facility.

3.3.3.3.2 Approach for Hydrology Evaluation

3.3.3.3.2.1 Identification and Basis for Hydrology Technical Issues

The Technical Guideline evaluation involves as a first step the identification of issues related to preclosure hydrologic conditions at the Yucca Mountain site. The main issues are based, principally, on interpretation of the qualifying and disqualifying conditions for the guideline. Also of interest are the results of the previous EA and pertinent work since the EA that support issue resolution.

The preclosure hydrologic issues were identified by a small group of technical experts after careful review of the guideline conditions and the EA. The following four issues were found to encompass an initially larger list of potential issues.

- <u>Technical Issue 1: Surface Flooding</u>

  Does the possibility exist for large surface runoff, including the potential for flooding, serious enough so as not to be accommodated by RAT, including the design of adequate seals for accesses to the underground facility?

- <u>Technical Issue 2: Ground-water Conditions</u>

  Is there RAT to design, construct and operate the underground facilities and sealing components, considering likely subsurface ground-water conditions?

- Technical Issue 3: Water Availability

  Is adequate water available for site characterization and repository development?

- Technical Issue 4: Water Rights

  If Yucca Mountain is selected for repository development and a permanent land withdrawal is then made, will the associated reservation of water rights represent an insurmountable impediment?

As previously mentioned, the wording for both the qualifying and disqualifying conditions is similar. Both conditions introduce the possibility of hydrologic threats to repository construction, operation, and closure and allow the use of RAT to counter these hazards. Issue 1 is derived from the qualifying condition and raises the potential for surface flooding beyond RAT, taking into account sealing capabilities. Issue 2 is based on both the qualifying and disqualifying conditions and raises concerns about whether ground water conditions could require technology that is not reasonably available. This issue specifically addresses the ability to develop adequate seals. Issues 3 and 4, involving the physical and legal availability of adequate water to develop the site, are inferred from the qualifying condition and the EA. Issue 4 is also addressed in Section 3.3.2.2, where the disqualifying condition for the Socioeconomic Impacts Guideline addresses water quality and quantity impacts.

3.3.3.3.2.2 Information or Actions to Resolve Hydrology Issues

Resolution of Technical Issue 1: Surface Flooding

This issue can be resolved if the potential threat of surface flooding can be accommodated by conservative design and location of specific ramps and/or shafts, as well as by the application of available sealing technology and standard engineering control measures. Flood potential information is available through Squires and Young (1984), Site Characterization Plan Conceptual Design Report (SCP-CDR) (SNL, 1987), and Bullard (1986). Likely locales for the facility are described in the Exploratory Shaft Alternative Configurations Study, (Dennis, 1991; Stevens and Costin, 1991). Reports by Fernandez et al. (1987) and Fernandez et al. (1988) provide evaluations of the requirements for sealing accesses to the underground facilities to counter surface flooding threats.

Resolution of Technical Issue 2: Ground-water Conditions

This issue can be resolved if the potential threat of underground flooding can be accommodated by standard engineering measures, sealing, and other RAT. The SCP-CDR (SNL, 1987) evaluates the subsurface flooding threat. Fernandez et al. (1987) evaluated techniques available to mitigate subsurface flooding conditions and to limit impacts on the underground facility.

Resolution of Technical Issue 3: Water Availability

This issue can be resolved if the water demand for repository development, including site characterization, is not expected to exceed available water supplies. The EA estimates of water requirements may need to be revised to reflect the latest analyses by Stevens and Costin (1991). The EA relied on well J-13 as the source for water to support site activities. That well, along with well J-12, remain as physically viable sources for the needed water.

Resolution of Technical Issue 4: Water Rights

This issue can be resolved if a number of viable alternatives exist for the federal government to acquire necessary water rights or if legal precedents exist that demonstrate successful acquisition of water rights.

3.3.3.3.3 Status of Current Hydrology Information

A summary of the current status for preclosure hydrologic issues is presented in this section. First, the EA conditions and findings for this guideline are reviewed; then, information that has been obtained since the publication of the EA is reviewed.

3.3.3.3.3.1 Summary of Environmental Assessment Findings for Hydrology

The EA evaluation of the Preclosure Hydrology Guideline is presented on pages 6-328 through 6-335 of that document (DOE, 1986). Table 3-3 provides a statement of the favorable, potentially adverse, qualifying, and disqualifying conditions and states the conclusion reached for each condition in the EA.

The EA discussed the technical issues associated with each of the hydrologic conditions specified in this guideline. In general, the technical evidence presented in the EA supports a position that the Yucca Mountain site is located in a region with favorable surface and subsurface hydrologic conditions. Neither the surface nor subsurface hydrology is expected to have a deleterious impact on construction or operation of the ESF or on repository construction, operation, and closure. In addition, the EA suggested there are water resources available in the vicinity of the Yucca Mountain site that are adequate to support ESF and repository-related activities.

The EA acknowledged the possibility for encountering localized perched-water zones between the land surface and the host rock, although such zones were considered unlikely. The point was made that existing drill holes demonstrate that no aquifers exist between the surface and the potential host rock. The EA also noted that ground-water conditions at Yucca Mountain will not expected to require complex engineering measures; sealing of shafts and boreholes was not expected to present engineering problems.

The potential for sheet flow and localized flash flooding through the ephemeral stream channels feeding Fortymile Wash during extreme storm events was recognized. The EA also noted that some portion of the surface

Table 3-3. Summary of Environmental Assessment Conditions and Findings for Hydrology (DOE, 1986)

Condition	DOE Finding
	FAVORABLE CONDITION
1. Absence of aquifers between the host rock and the land surface.	The evidence indicates that this favorable condition is present at Yucca Mountain: the host rock is above the water table.
2. Absence of surface-water systems that could potentially cause flooding of the repository.	The evidence indicates that this favorable condition is not present at Yucca Mountain: there are no perennial stream channels that could potentially flood the repository; however, rare extreme storms could result in flooding of the repository surface facility and access routes due to sheet flow.
3. Availability of the water required for repository construction, operation, and closure.	The evidence indicates that this favorable condition is present at Yucca Mountain: sufficient ground-water is expected to be available from nearby wells.
	POTENTIALLY ADVERSE CONDITION
1. Ground-water conditions that could require complex engineering measures that are beyond reasonably available technology for repository construction, operation, and closure.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: the potential repository is above the water table and no significant amounts of ground water are expected; shafts and boreholes are expected to be adequately sealed with available technology.
	QUALIFYING CONDITION
1. The site shall be located such that the geohydrologic setting of the site will (1) be compatible with those activities required for repository construction, operation, and closure;	Available evidence does not support the finding that the site is not likely to meet the qualifying condition (Level 3): host rock is above the water table; wells are expected to provide adequate water supply; there are no surface-water

Table 3-3. Summary of Environmental Assessment Conditions and Findings for Hydrology (DOE, 1986) (continued)

Condition	DOE Finding
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.	systems that could flood the repository or compromise shaft liners and seals; and transient runoff will be adequately handled with routine drainage control measures.
DISQUALIFYING CONDITION	
1. 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.	The evidence indicates that it is highly unlikely that significant amounts of ground water will be encountered during the construction of the exploratory shaft and during repository construction, operation, and closure. Currently available engineering measures are considered more than adequate to guarantee that no disruption of construction and operation will occur because of ground-water conditions at Yucca Mountain. Therefore, evidence does not support a finding that the site is disqualified (Level 1).

facilities might be located in areas that could be affected by the extreme flooding represented by the Regional Maximum Flood (Squires and Young, 1984).

The EA concluded that currently available engineering measures are more than adequate to guarantee that construction and operation will not be disrupted because of ground-water conditions at Yucca Mountain. Reasonable drainage control measures are expected to provide adequate protection against sheet flow and flash flooding, adequate sealing technologies are available and water supplies are available to meet projected repository requirements without affecting regional availability.

3.3.3.3.3.2 Information on Hydrology Acquired since the Environmental Assessment

This current evaluation reexamines the issues raised in the EA and considers more recent evidence and analyses. No significant errors or inconsistencies were identified in the original EA evaluation to date, and recent studies confirm and strengthen the original EA findings.

Options for the configuration and layout of the Exploratory Studies Facility (ESF) have been evaluated (Dennis, 1991; Stevens and Costin, 1991). Alternative means of access to the potential host rock and alternative construction technologies were evaluated in addition to evaluations of the complex interactions between the testing program and the construction schedules and operations. Although the ESF represents only a small portion of the repository area, the construction techniques and technology are expected to be representative of the technology applied and problems faced in the future repository construction effort. The recent evaluation developed thirty-four unique ESF/repository configurations and used a decision-aiding methodology to rank these options. The final ranking of these options is described in Stevens and Costin (1991) and further documented in Dennis (1991). The DOE decided to proceed with the development of a reference configuration based on option #30, which is shown in Figure 3-2. As shown in Figure 3-2, the reference configuration consists of a waste ramp in the northeast, a tuff ramp in the southeast, an emplacement exhaust shaft in the northeast, and a men-and-materials shaft in the south. The mining method for the ESF and the potential repository could use tunnel-boring machines or other viable technologies. The location of the surface facilities is unchanged from the SCP-CDR (SNL, 1987) (located in the northeast).

Although differences exist between the current reference configuration and option #30, they are not expected to alter the arguments relating to the Preclosure Hydrology Guideline. These differences include moving the main test level (MTL) from the north to the south portion of the potential repository area. Also, an alternate shaft is being considered for possible use during the site characterization phase.

Other information since the EA includes studies by Fernandez et al. (1987), Case and Kelsall (1987), and Fernandez et al. (1988). These studies evaluate the potential impacts of surface runoff and subsurface water on access construction and sealing and on underground construction and sealing. Fernandez et al. (1987) was written to support the advanced conceptual design as described in the SCP-CDR. The specific objectives of this study were to develop performance goals for the repository (including shafts and portals), to assess the need for seals by evaluating expected water inflows, and to define design requirements and sealing materials that could satisfy the performance goals given the expected hydrologic conditions at the repository site. Case and Kelsall (1987) evaluated modifications to rock mass permeabilities in the zone surrounding a shaft in welded tuff. Fernandez et al. (1988) was written specifically to evaluate the impact of the construction of two large-diameter shafts on the long-term waste isolation capability of the repository. The analyses focused on the zones of increased rock damage surrounding the shaft liners and the potential influence of this damage on long-term isolation capabilities when the region is subjected to a Probable Maximum Flood (PMF). New PMF discharges have been calculated since the EA (Bullard, 1986) using ANSI/ANS procedures (ANSI/ANS,1981), but specific flood inundation areas for Yucca Mountain have not been determined.

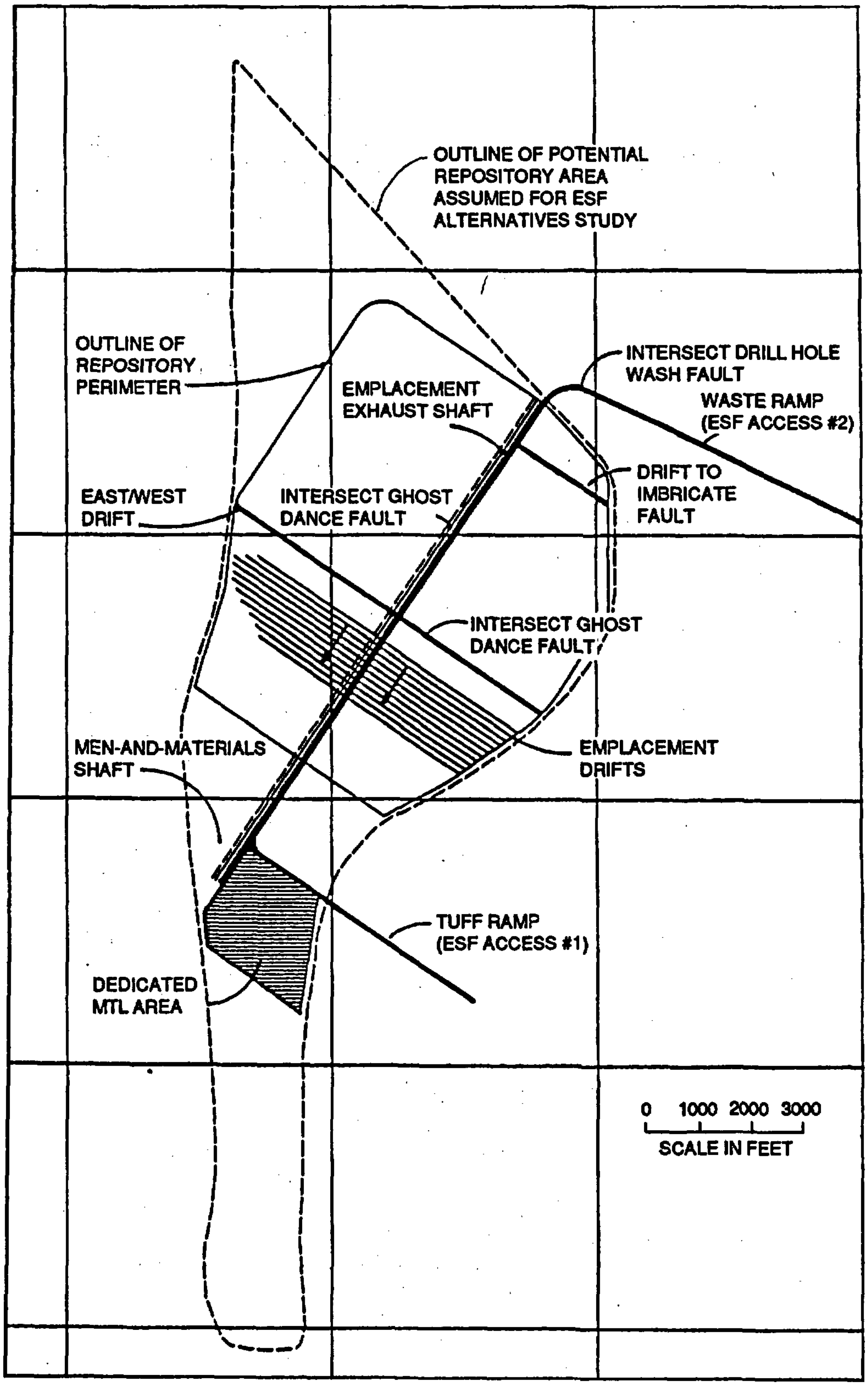


Figure 3-2. Reference configuration for Exploratory Studies Facility and Repository (Option #30).

Perched-water bodies within an unsaturated-zone environment are inherently unstable and will tend to dissipate unless sustained by an influx of water. Because of the present aridity of the region, water is not expected to enter the unsaturated zone in sufficient quantities to create and sustain extensive perched-water bodies within the deep unsaturated zone at the Yucca Mountain site. However, localized regions of perched water have been observed to occur within the near-surface environment and, possibly, may occur at depth in highly fractured zones in response to episodic, high-intensity infiltration events. An apparent perched-water body was encountered during dry (air) drilling of borehole USW UZ-1 at the Yucca Mountain site. Water samples, however, indicated that the water entering UZ-1 was contaminated with drilling fluid, and it was concluded that this water had migrated to the location of UZ-1 as the result of drilling of nearby borehole USW G-1 (Whitfield et al., 1990). Perched water, if encountered, is not expected to pose any problems that cannot be accommodated by RAT.

3.3.3.3.4 Current Status of Hydrology Technical Issues

Using the information acquired since the EA, the status of remaining technical issues related to preclosure hydrology has been examined. The following represents the consensus of the Core Team.

- Technical Issue 1: Surface Flooding

  Does the possibility exist for large surface runoff, including the potential for flooding serious enough so as not to be accommodated by RAT, including the design of adequate seals for the accesses to the underground facility?

The threat of flooding is discussed by Squires and Young (1984) and in the SCP-CDR (SNL, 1987, Chapters 2 and 7). Option #30, the current reference repository configuration, used the information from Squires and Young (1984) to site shaft collars and ramp portals outside regions identified as possible flood areas. As a consequence, the emplacement, exhaust, and men-and-materials shafts were moved to higher elevations in the options study to mitigate the risks of flooding. The waste ramp and waste-handling facilities remained in their previous (SCP-CDR) locations, which are protected from sheet flow with protective dike structures. The tuff ramp location in the southeast was also sited to be outside the region of the PMF for that location. Potential alterations to the configuration being considered by the DOE, including other ramp portal and shaft collar locations, will be carefully scrutinized with regard to flooding potential and are expected to be sited in locations that are not threatened by surface flooding. In any case, careful selection of collar and portal locations along with prudent engineering measures (as described in Fernandez et al., 1987; Fernandez et al., 1988) can easily mitigate any potential surface flooding conditions.

- Technical Issue 2: Ground-water Conditions

  Is there RAT to design, construct, and operate the underground facilities, including sealing components, considering likely subsurface ground-water conditions?

The proposed host rock for the potential repository is within the Topopah Spring Member of the Paintbrush Tuff at an altitude ranging from 200 to 400 m above the local water table (SNL, 1987). Option #30, the current reference repository configuration, locates the repository at an altitude of 558 ft to 1,180 ft above the water table and underlying drifts in the Calico Hills at approximately 644 ft above the water table. Therefore, the threat from subsurface water is primarily from possible perched water bodies that might be encountered during excavation of the underground openings. There is no direct evidence that perched-water zones exist within the region proposed for the repository. This does not preclude the possibility that some zones of saturation may exist within fault zones or beneath areas of infiltration of surface runoff. As described earlier, perched water, even if encountered, is not expected to pose problems that cannot be overcome by RAT.

- Technical Issue 3: Water Availability

  Is adequate water available for repository development?

The EA describes yields of ground water from well J-13 of 600 gallons per minute with no apparent drop in water table altitude. The current estimate of water required for the surface-based investigations programs is 37,200 gallons per day (Gertz, 1991). The estimate for water consumption for lifetime repository construction and operation for the SCP-CDR design is 432,000 m^3 (350 acre-feet) (Morales, 1985). Preliminary estimates for the option #30 reference configuration for repository construction, operation, and closure is about 2,365,000,000 gallons (8,951,000 m^3) (Dennis, 1991). These estimates appear to be within the range of water capacities for well J-13 (Thordarson, 1983).

- Technical Issue 4: Water Rights

  If Yucca Mountain is selected for repository development, and a permanent land withdrawal is then made, will the associated reservation of water rights represent an insurmountable impediment?

This issue addresses the possibility that reservation of water rights for Yucca Mountain will constitute an insurmountable legal impediment resulting in the DOE not being able to procure the water rights necessary to characterize and develop the site. If Yucca Mountain is selected for repository development, the federal government will have to make a permanent land withdrawal for that purpose. Legal precedents (e.g., U.S. vs. New Mexico, 438 U.S. 696 [1978]) establish the case law doctrine that this federal reservation implies that a reservation of water necessary to fulfill the purpose of the reservation is also made. In addition, the President's proposed National Energy Strategy Act calls for amending the Nuclear Waste Policy Act to alleviate permitting delays from State or local authorities by exempting the DOE from State environmental laws, including the water appropriation permitting process. The proposed legislation, however, applies only to the site characterization phase of the program. But a similar process could eventually be pursued for repository construction, operation, closure, and decommissioning if the existing process became an insurmountable impediment to proceeding with the program.

Alternative courses of action are available to the DOE to overcome this legal impediment: (1) the water permit application with the State can be pursued; (2) as described above, Congressional action can proceed to expressly reserve water for site characterization and development; and (3) where practicable, water can be purchased from sources that have no restriction on the place or type of use.

In summary, acquisition of water rights by the Federal government can successfully proceed by a variety of approaches. This issue appears resolvable and is not expected to represent an insurmountable impediment for the potential repository site.

3.3.3.3.5 Conclusions and Recommendations for Future Hydrology Activities

The consensus of the Core Team is that preclosure hydrologic issues for the Yucca Mountain site are not expected to constitute serious problems and can be accommodated using standard engineering control measures and RAT. A higher-level suitability finding is therefore supported for both the qualifying and disqualifying conditions for this guideline. Additional tests and data collection at the site and further design analysis relative to the planned facilities should continue on a confirmatory basis. Technology and design developments are also expected to continue to enhance the current confidence in the higher-level findings.

Activities described in the SCP (DOE, 1988a) will provide additional assurance to support the recommendations in this report. Planned studies of transport of debris by severe runoff and of site flood and debris hazards will provide information on the quantities and characteristics of debris that might be eroded, transported, and redeposited by flood flows.

3.3.3.4 PRECLOSURE TECTONICS TECHNICAL GUIDELINE

3.3.3.4.1 Statement and Discussion of Qualifying and Disqualifying Conditions

Qualifying Condition [10 CFR 960.5-2-11(a)]: "The site shall be located in a geologic setting in which any projected effects of expected tectonic activity on repository construction, operation, and closure will be such that the requirements specified in Section 960.5-1(a)(3) can be met."

Disqualifying Condition [10 CFR 960.5-2-11(d)]: "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 the exploratory shaft construction or for repository construction, operation, or closure."

Discussion. This guideline covers tectonic hazards during the construction, operation, and decommissioning of a repository. An objective of the Preclosure Tectonics Guideline is to ensure that a site for a repository is located in a geologic setting where any expected tectonic effects during the preclosure period will be such that they will not require design features or measures beyond reasonably available technology.

3.3.3.4.2 Approach for Preclosure Tectonics Evaluation

3.3.3.4.2.1 Identification and Basis for Preclosure Tectonics Technical Issues

This technical guideline evaluation involves, as a first step, the identification of issues related to preclosure tectonics at the Yucca Mountain site. The technical issues of interest may include environmental and institutional concerns. They are based, principally, on interpretation of the qualifying and disqualifying conditions for the guideline. Also of interest are the results of the Environmental Assessment (EA) (DOE, 1986) and pertinent work completed since the EA was issued that supports issue resolution, both of which are summarized in Section 3.3.3.4.3 of this report. A larger initial list of potential issues was found to be encompassed by the following four issues:

- Technical Issue 1: Ground Motion

  What is the expected ground motion at the Yucca Mountain site and can it be accommodated with reasonably available technology (RAT) without loss of integrity of structures, systems, and components important to safety?

- Technical Issue 2: Surface Displacement

  What is the expected surface displacement at the Yucca Mountain site and can it be accommodated with RAT without loss of integrity of structures, systems, and components important to safety?

- Technical Issue 3: Seismic-Induced Surface Failures

  Is the hazard from seismically induced failure of soil deposits (e.g., landslides, slumps, or liquefaction) sufficiently low to be discounted during the preclosure period, considering RAT?

- Technical Issue 4: Volcanic Hazard

  Is the volcanic hazard sufficiently low to be considered not significant during the preclosure period?

The wordings for the qualifying and disqualifying conditions for this guideline are quite similar. Both conditions introduce the possibility of ground motion and surface displacement; both conditions allow for RAT to counter these potential hazards. Issues 1 through 3, therefore, relate to both the qualifying and disqualifying conditions. Issue 4 refers to the specific identification of the broader tectonic hazards as required by the qualifying condition.

3.3.3.4.2.2 Information or Actions to Resolve Preclosure Tectonics Issues

Resolution of Technical Issue 1: Ground Motion

This issue can be resolved if it can be determined that the proposed repository, designed on the basis of RAT, can accommodate the expected ground motion at the Yucca Mountain site without loss of integrity of the surface and underground structures, systems, and components. Important studies addressing this concern include Subramanian et al. (1989 and 1990) and Subramanian (1989). The hazard from seismic loading during the preclosure period is thought to be greater for the surface facilities than for the underground facilities. Of the structures within the surface facilities, the waste handling building is critical. Subramanian et al. (1989) estimated the optimum design level for the waste handling building and predicted the likelihood of different amounts of damage for given peak ground accelerations.

Several deterministic and probabilistic seismic hazard analyses for the Yucca Mountain site have been performed since the EA. Two key studies for earthquake hazards at the surface facilities are URS/Blume (1986) and URS/Blume (1987). Satisfactorily combining the ground motion hazard with the design response should help resolve Technical Issue 1.

Resolution of Technical Issue 2: Surface Displacement

This issue can be resolved if it can be shown that the expected surface displacement at the Yucca Mountain site can be accommodated by RAT without loss of integrity of structures, systems, and components important to safety for both surface and underground facilities. Important studies that address this concern are Subramanian et al. (1989, 1990) and Subramanian (1989). Those studies estimated the response of surface structures to surface displacement. Fault movements similar to those expected at the surface must be accounted for in the design of the underground facilities.

Satisfactorily combining the ground-rupture hazard with the design response should help resolve Issue 2.

Resolution of Technical Issue 3: Seismic-Induced Surface Failure

This issue can be resolved if the likelihood of seismically induced failure of soil deposits beneath the potential waste-handling facilities is small, and potential failures can be accommodated by RAT. Ho et al. (1986) discuss the suitability of natural soils for foundations of the surface facilities. These authors discount the hazard of liquefaction and settlement for the waste handling building. Recent work on the Exploratory Shaft Facility Design Requirements (DOE, 1990b) shows that only credible disruptive events may need to be considered.

Resolution of Technical Issue 4: Volcanic Hazard

This issue can be resolved if the probability of a volcanic event during the preclosure time frame is sufficiently low that it is unlikely to cause a significant release from the proposed repository. Given that it is appropriate to calculate the rate of volcanism in the area based on the the last 4 million years of the geologic record, the work of Crowe et al. (1982; 1983a) and Perry and Crowe (1990) can be used to estimate the probability of a volcanic eruption that would disrupt the site prior to closure.

3.3.3.4.3 Status of Current Preclosure Tectonics Information

A summary of the current status for preclosure tectonics is presented in two sections. First, the EA conditions for this guideline are presented; then, information that has been obtained since the EA was published is reviewed.

3.3.3.4.3.1 Summary of Environmental Assessment Findings for Preclosure Tectonics

This guideline consists of one favorable condition, three potentially adverse conditions, a qualifying condition, and a disqualifying condition. The conditions and the U.S. Department of Energy (DOE) findings in the EA for these conditions are provided in Table 3-4.

According to the evidence presented in the EA, Yucca Mountain does not possess the favorable condition for preclosure tectonics. In addition, potentially adverse condition 1 is present at the site. However, the presence of a potentially adverse condition does not mean that the site is disqualified, but only that an understanding of that condition would be needed so that repository design and operation could mitigate its effects. Despite possessing one of the potentially adverse conditions and not satisfying the favorable condition, the understanding of the tectonic framework at Yucca Mountain was adequate to support lower-level suitability findings for both the qualifying and disqualifying conditions for preclosure tectonics in the EA.

Table 3-4. Summary of Environmental Assessment Findings for Preclosure Tectonics (DOE, 1986)

Condition	DOE Finding
QUALIFYING CONDITION	
1. The site shall be located in a geologic setting in which any projected effects of expected tectonic or igneous activity on repository construction, operation, and closure will be such that the requirements in Section 960.5-1(a)(3) can be met.	Existing information does not support the finding that the site is not likely to meet the qualifying condition (Level 3): tectonic-induced ground motion at the site is expected to be within reasonable design levels for a nuclear specified facility; there is about a 1 chance in 10,000 for igneous activity over a 10,000-year period. The projected effects of either tectonic or igneous activity in a 90-year period of repository construction, operation, and closure are not likely to be significant.
DISQUALIFYING CONDITION	
1. 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 the exploratory shaft construction or for repository construction, operation, or closure.	The evidence does not support a finding that the site is disqualified (Level 1). Based on the DOE's current understanding of tectonic activity at Yucca Mountain, the design parameters for such potential hazards are well within the limits of reasonable available technology.
FAVORABLE CONDITIONS	
1. The nature and rates of faulting, if any, within the geologic setting are such that the magnitude and intensity of the seismicity are significantly less than those generally allowable for the construction and operation of nuclear facilities.	The evidence indicates that this favorable condition is not present at Yucca Mountain: the predicted magnitude and intensity of associated seismicity are expected to be acceptable but not expected to be significantly less than those generally allowable for the construction of nuclear reactors.

Table 3-4. Summary of Environmental Assessment Findings for Preclosure Tectonics (DOE, 1986) (continued)

Condition	DOE Finding
POTENTIALLY ADVERSE CONDITIONS	
1. Evidence of active faulting within the geologic setting.	The evidence indicates that this potentially adverse condition is present at Yucca Mountain: evidence of active faulting and ground-surface displacement is found within the geologic setting.
2. Historical earthquakes or past man-induced seismicity that, if either were to recur, could produce ground motion at the site in excess of reasonable design limits.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: historical earthquakes and past man-induced seismicity are not expected to cause ground motion at the site that would exceed reasonable design limits.
3. Evidence, based on correlations of earthquakes with tectonic processes and features (e.g., faults) within the geologic setting, that the magnitude of earthquakes at the site during repository construction, operation, and closure may be larger than predicted from historical seismicity.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: no evidence exists to suggest that earthquakes larger than those predicted from historical seismicity could occur during repository construction, operation, and closure.

Information Supporting Environmental Assessment Findings for Preclosure Tectonics

The information and conclusions presented in the EA for preclosure tectonics can conveniently be grouped into seismic and volcanic hazards.

Seismic Hazard Considerations: Conclusions presented in the EA were based on the position that earthquakes expected at or near Yucca Mountain during the preclosure period are small-magnitude ($M \leq 4$) and are well within RAT. Data supporting this position included historical seismicity, recent seismicity as recorded on instrumented seismic networks, paleoseismic studies, and regional geologic mapping. As described in the EA, the Nevada Test Site (NTS) region occupies an intermediate position between a large area of higher seismicity to the north and an area of lower seismicity in the Las Vegas region to the south (see Figure 3-3). Except for a cluster of seismicity due to the water load of Lake Mead, the figure shows a fan-shaped region extending southeast from the repository site that is virtually free of earthquakes of M=4 or larger. The U.S. Geologic Survey (USGS) (1984) calls attention to the near absence of seismicity at approximately the M>4 level in some parts of a 100-km (60-mile) radius surrounding the site.

Basic assumptions of the EA are that the rate and style of tectonic activity during the preclosure period will be similar to that during the historical record and that the likelihood of a larger-than-historic event is low during the preclosure period. The EA cites recurrence intervals in a 34,000 km^2 area, including the NTS, of about 25,000 years for M≥7 earthquakes; 2,500 years for M≥6 earthquakes; and 250 years for M≥5 earthquakes (Greensfelder et al., 1980). The EA also indicated that although fault movements large enough (M=6-6.5) to cause surface displacements are possible (USGS, 1984) at or near the site, recurrence interval data suggest such displacements are unlikely for the preclosure time period of 100 years.

Uncertainties in the basic assumptions mentioned above derive mainly from two factors: (1) the historical record of earthquake activity is only approximately 100 years long, and (2) the regional instrumented seismic network at Yucca Mountain has been in place only since 1978.

Seven historical earthquakes were reported within 10 km of Yucca Mountain before 1978; two of these had magnitudes of M=3.6 and M=3.4. The magnitudes of the remaining 5 were not reported; they were apparently very small or had magnitudes that could not be estimated because of instrument problems. A regional seismic network established in 1978 recorded 3 micro-earthquakes within 10 km of Yucca Mountain between August 1978 and the end of 1983. The largest magnitude of these microearthquakes was approximately M=2. No historical earthquakes of M≥6 have occurred within 100 km of the site. Other uncertainties occur in the relationships of fault length to earthquake magnitude and earthquake magnitude to accompanying ground motion.

As reported in the EA, the peak historical ground acceleration related to earthquake sources recorded near Yucca Mountain was estimated by Rogers et al. (1977) at less than 0.1g. In 1984, the USGS (1984) deterministically estimated the most likely peak acceleration at Yucca Mountain would be approximately 0.4g. This acceleration is based on a rupture of the entire length of the Bare Mountain Fault, located 14 km west of Yucca Mountain. In a separate probabilistic analysis, the USGS (1984) predicted an earthquake resulting in 0.4g ground acceleration at Yucca Mountain has a return period of 900 to 30,000 years. Assuming a 90-year lifetime of the surface facilities, the probability of exceeding 0.4g ground acceleration ranges from 3×10^{-3} to 10^{-1}.

The EA also briefly reviewed seismic design considerations for both the surface and underground portions of the repository. Some studies were done specifically for the Yucca Mountain site (e.g., Owen et al., 1980; MacDougall, 1985), while others offer a basis of comparison with other structures found in seismically active areas (e.g., Pratt et al., 1978). The EA considered the questions that would be raised in design and licensing for

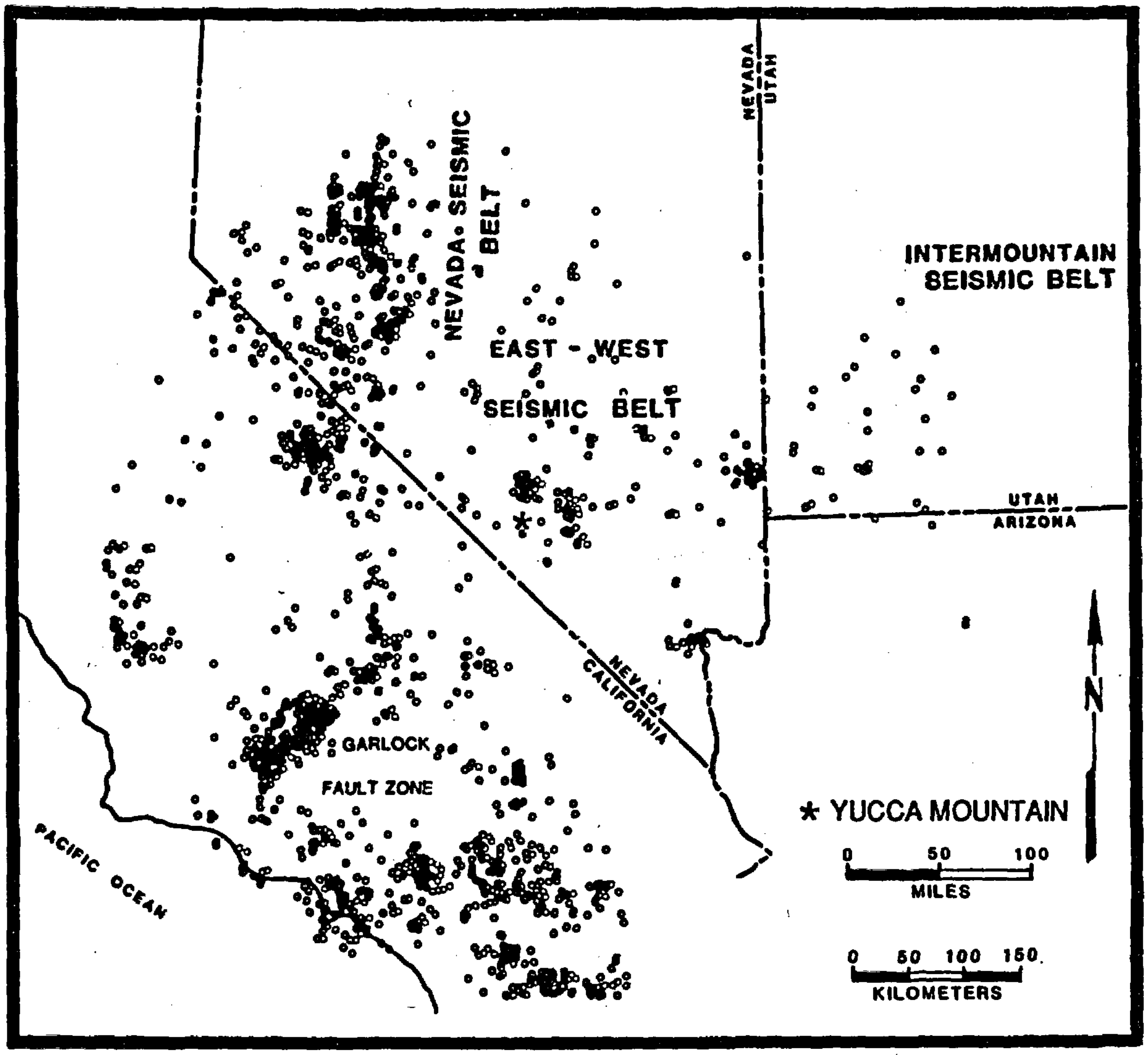


Figure 3-3. Historic earthquakes of Mercalli intensity ≥ V or Richter magnitude ≥ 4.0 within 500 kilometers (311 miles) of the Yucca Mountain site through 1974. Those circles that appear solid indicate multiple events (modified from USGS, 1984).

a waste handling facility that spans a fault with the potential for significant surface displacement. The EA also listed facilities throughout the world that were designed for and have experienced strong ground motion or fault movement, along with the source of the ground motion and the observed effects. These facilities can be used as analogs for the surface facilities at Yucca Mountain. Damage to underground facilities is typically less than for surface facilities. The EA reports that the primary causes of failure in underground excavations are movement along pre-existing faults and collapse of openings, especially the portal to ramps or shafts.

Volcanic Hazard Considerations: The volcanic hazard discussion in the EA was detailed in connection with the Postclosure Tectonics Guideline evaluation in Section 2.3.7. The probability that basaltic volcanism will occur at the Yucca Mountain site over a 10,000-year period was estimated to be about 1 chance in 10,000 (DOE, 1986). The consequences of such a basaltic event are assessed by Link et al. (1982).

The conditional probability for the recurrence of a volcanic event, and for that event to disrupt an underground repository at Yucca Mountain was estimated in the EA to be between 10^{-8} to 10^{-10} per year (Crowe et al., 1982). On the basis of information available at the time of the EA, the probability of a recurrence of basaltic volcanism that causes disruption of the repository facility lies between 3.3×10^{-6} and 3.0×10^{-8} for the 90-year preclosure period (DOE, 1986).

3.3.3.4.3.2 Information on Preclosure Tectonics Obtained since the Environmental Assessment

The EA cited references prior to early 1986. Emphasis is placed here on reviewing work completed since that date and on evaluating how that work contributes to resolution of remaining tectonic issues. Publications since the EA describe advances in three general areas: (1) Quaternary geology in the Yucca Mountain area; (2) methodologies for seismic hazard analysis, particularly in probabilistic and combined deterministic-probabilistic assessments; and (3) seismic design of the repository.

(1) Quaternary Geology in the Yucca Mountain Area

Nature and Age of Fault Movement: Suitability of this site partly depends on predictions of its future tectonic stability. This stability can be fully evaluated only after the structures at Yucca Mountain, in particular Quaternary faults, are understood.

Three major Quaternary/Tertiary stratigraphic divisions were defined initially by Hoover and Morrison (1980) for the NTS region. A summary of detailed Quaternary stratigraphy of the Yucca Mountain region is presented by Hoover et al. (1981), building on Hoover and Morrison (1980), Bull and Ku (1975), and Morrison (1967). Swadley and Hoover (1983) and Swadley et al. (1984) retain the stratigraphy of Hoover et al. (1981) to describe the Quaternary stratigraphy in the NTS area and at Crater Flat, to the west of Yucca Mountain, primarily for use in fault studies. Hoover (1989) elaborates on the work of Hoover et al. (1981), retaining the established stratigraphy while modifying the assigned ages of stratigraphic units proposed by Swadley et al. (1984).

Three major late Cenozoic stratigraphic units in the NTS region have been differentiated using the concept of correlation characteristics (Hoover et al., 1981; Hoover, 1989), which uses physical and morphologic characteristics of landscape elements, including landform, drainage network, soils, topographic position, desert pavement, desert varnish, depositional environment, and lithology. The oldest surficial unit, QTa, is Quaternary (early Pleistocene) and/or Tertiary (Pliocene) in age. Units Q2 and Q1 represent middle to upper Pleistocene and Holocene deposits, respectively. A total of 10 subunits of Q1 and Q2, and possibly three additional subunits of uncertain age that may belong in unit Q2 are locally mapped in the NTS region (Hoover et al., 1981, p 8). Swadley and Parrish (1988) mapped most of Crater Flat and part of Amargosa Valley (Swadley and Carr, 1987) using this stratigraphy.

Taylor (1986) studied fluvial, debris flow, eolian, and sheetwash deposits along Yucca and Fortymile Washes to (1) assess the influence of time and climate on soil development and (2) model calcic horizon development to quantify the variability in past Quaternary climates of the area. Taylor (1986) adopts, with minor modification, the Quaternary stratigraphic framework of the NTS region that was developed by Hoover et al. (1981) and Swadley (1983). Twenty backhoe trenches were excavated on the stable parts of fluvial terraces and alluvial fan surfaces for the Taylor study. Taylor describes six Tertiary-to-Quaternary geologic units along Yucca and Fortymile Washes. Ages of map units were assigned based on correlation with the stratigraphy and dates of Hoover et al. (1981), Szabo et al. (1981), and Swadley and Hoover (1983). Taylor (1986) demonstrates that age correlates with soil morphology and the progressive accumulation of secondary silica, carbonate, and clay.

Peterson (1988) conducted reconnaissance soil-geomorphic studies in the Crater Flat area, less than 5 km west of Midway Valley, to evaluate previous studies (Note: Midway Valley is the location of the potential surface facilities). He identifies five geomorphic surfaces and assigns ages to them based on radiocarbon dating of desert varnish, varnish cation ratio (VCR) dating, relative geomorphic position, and soil development. The accuracy of the VCRs used in this study have been analytically criticized by Bierman and Gillespie (1991).

On the basis of their preliminary mapping of the Midway Valley area at the eastern base of Yucca Mountain, Wesling et al. (in preparation) have differentiated ten surficial geological map units. These include remnants of eight separate alluvial-fan and terrace surfaces, including the modern fluvial surfaces; undifferentiated colluvium and debris-flow deposits that lie along the base of and mantle the lower slopes of the hills bounding Midway Valley; and the adjacent bedrock terrain, consisting of bedrock exposures and bedrock mantled by thin talus and colluvium deposits. Map units are defined on the basis of landform morphology, relative soil development, distinctive drainage patterns and/or density, and associated characteristics, such as type and density of vegetation. No correlation is presented by Wesling et al. (1991) to the stratigraphy of Hoover (1989).

The possibility of time-transgressive relationships within the stratigraphy of Hoover, Swadley, and other USGS workers cannot be ruled out. Many researchers believe that the techniques used to date Quaternary deposits, including those units at the NTS, are less reliable than they were believed to be five to ten years ago (e.g., Bell et al., 1988). Increased uncertainty in the age of offset deposits leads to increased uncertainty in estimates of timing and rates of movements of faults in the Yucca Mountain area.

Section 2.3.7.3.2.1 of this report provides a discussion of the range of tectonic models that could explain the geometry of faults in the Yucca Mountain area (see also Carr, 1984, 1990; Yount et al., 1987; Hamilton, 1988; Rosenbaum and Hudson, 1989; Scott and Bonk, 1984; Scott and Whitney, 1987; Scott, 1988 and 1990). The major north-trending faults that transect Yucca Mountain may be planar or listric. If listric, they may bottom into a regional detachment zone. This regional detachment zone could act as a direct couple between listric faults on which displacements could then occur simultaneously. Multiple faults may act together during an earthquake, causing distributive faulting that could release more seismic energy over a wider area than a single event on a single fault trace (Ramelli et al., 1988; Ramelli et al., 1989).

Rates of Quaternary movement have been calculated in several places where data are available on major faults. Rates for the Paintbrush Canyon, Windy Wash, and Stagecoach Road faults are >0.006, >0.015, and >0.003 mm per yr., respectively (Scott, 1990). Work by Whitney et al. (1986) on the Windy Wash Fault indicates seven episodes of movement during the Quaternary, including one episode during the past 10,000 years. Reheis (1988) also shows that faults with Holocene displacement bound the east side of Bare Mountain. In general, most north-trending faults at Yucca Mountain have experienced multiple displacements during the Quaternary Period. The timing and rate of this seismic activity is important to understanding the seismic hazard to the surface facilities and the degree to which RAT can accommodate this activity. Additional paleoseismic studies are needed to reduce current uncertainties with respect to likely earthquake activity near and at the site.

Note that multiple tectonic models exist for Yucca Mountain. Some of these models involve strain partitioning or decoupling of the upper and lower crust. Strain rates in the lower crust may be different than those in the upper crust; seismogenic sources at depths not yet accounted for could conceivably result in a higher seismic hazard from ground motion than would be obtained from paleoseismic and historical seismicity studies [see Section 2.3.7.3.2]. These uncertainties should be accounted for in future seismic hazard analyses. In addition, other crustal models have been postulated that suggest regional stresses may be oriented such that strike-slip movement on faults may be the dominant slip component. Paleoseismic data and historical earthquake studies will be needed to evaluate the likelihood of strike-slip faulting as the dominant slip component, and to evaluate the probability of distributed faulting within the repository and at the surface facilities.

Nature and Age of Volcanic Activity: Discussion continues on the age of Quaternary basaltic units of the Lathrop Wells cone. Certain lines of evidence, such as thermoluminescence, cosmogenic chlorine-36, geomorphology, and soil development, suggest a young, perhaps even Holocene, age for this cone and a polycyclic eruptive history (e.g., Wells et al., 1988; 1990; Crowe et al., 1989). Evidence from other dating techniques, including potassium-argon (K-Ar) and paleomagnetism, suggest an age of at least 100,000 years and a monocyclic eruptive scenario (Champion, 1991; Turrin and Champion, 1991). The order-of-magnitude difference in the age of the volcanic units results in an increased uncertainty in the rate of magmatic production, a basic parameter for volcanic hazard calculations. Even including the younger ages of eruption of the Lathrop Wells cone in the volcanic hazard calculations, the hazard posed by local basaltic volcanic processes remains small but should be reexamined and recalculated, if necessary, as new data are acquired (see Perry and Crowe and Perry, 1990). Crowe (personal communication, 1991) estimates a probability of 3×10^{-5} for disruption of the surface facility due to volcanic activity during the 100-year preclosure period.

(2) Methodologies for Seismic Hazard Analysis

Recent methodologies for assessing seismic hazards advocate a probabilistic or composite deterministic-probabilistic approach (Benjamin and Associates, Inc. et al., 1988a,b; National Research Council, 1988). Both deterministic (USGS, 1984) and probabilistic studies (Rogers et al., 1977; Perkins et al., 1986; URS/Blume, 1986, 1987) have been performed at Yucca Mountain. URS/Blume (1986) describe earthquake occurrence in terms of areally distributed source regions rather than specific fault sources. Earthquake occurrence rates were determined by broad spatial averaging of historic seismicity and paleoseismicity. They considered it premature to attempt assignment of seismicity on a fault-specific basis because of the limited fault data.

The URS/Blume (1986) study evaluated the potential ground motion at Yucca Mountain and its effect on siting and design of a nuclear waste repository. Two levels of ground motion for seismic design were proposed: (1) a higher level for design of facilities classified as important to offsite radiological safety, based on a 2,000-year return period, and (2) a lower level for on-site safety, based on a 500-year return period. Probabilistic analyses yielded horizontal peak accelerations of 0.25g and 0.4g for the 500-year and the 2,000-year events, respectively. Analyses of horizontal peak ground acceleration (PGA) were also conducted for underground nuclear explosions (UNE) at the NTS. Peak ground acceleration levels for design UNEs were less than those for design earthquakes. The horizontal response spectra for the two types of sources differed significantly. New work on crustal models by Walck and Phillips (1990) may necessitate some revision of response studies performed by URS/Blume. URS/Blume (1986) also presented results on the dynamic response of candidate sites for surface facilities and the type of data required in seismic design of underground facilities.

A second study by URS/Blume (1987) estimated the sensitivity of seismic hazards to various geologic parameters. These authors postulated a correlation between apparent vertical slip rate and mapped fault length. Correlations with power-law exponents of 1 through 3 were used to model varying relative activities of short and long faults. Two alternative interpretations were considered: one assuming pure normal-slip and another assuming oblique-slip on the fault. Displacement and acceleration hazards were estimated for the Yucca Mountain site. The predicted ground motion hazard in this analysis was dominated by the Paintbrush Canyon fault (DOE, 1988a), instead of the Bare Mountain fault, which had been used in the USGS (1984) deterministic study as the dominant seismogenic fault. The resulting expected ground motions were very sensitive to the assumed slip-rate. Other parameters used in the hazard assessment, such as regional seismic quality factor (Q) in the attenuation function, had little effect on the resultant hazard.

Surface-rupture calculations were made by URS/Blume (1987), using a joint probability for surface-rupture displacement, length, and rupture radius, combined with the fault-related earthquake recurrence models. Similar to the ground-motion hazards, surface-rupture hazards associated with the Paintbrush Canyon and related faults were most sensitive to the slip-rate function and relatively insensitive to the (downdip) fault width. These calculations stressed the importance of slip-rate determinations on both ground motion and surface-rupture-hazard assessments.

(3) Seismic Design of the Repository

Subramanian et al. (1989) performed a cost/benefit analysis, factoring various changes into the seismic design of the waste-handling facilities. Their findings were based on a combination of expert judgment and quantitative analysis. Values of vibratory ground-motion design levels from 0.2 to 1.0g and fault displacements beneath the foundations of the buildings from 0 to 100 cm were considered.

Costs were divided into accident and nonaccident-related costs. Accident-related attributes included probabilistically-derived costs for (1) public radiological exposure, (2) worker radiological exposure, (3) offsite property damage and cleanup, (4) onsite damage, including repairs and decontamination, and (5) mission delays. Attributes not related to accidents included (1) structural design and construction costs, (2) equipment procurement and qualification costs, (3) licensing costs, (4) site characterization costs, and (5) costs of potential programmatic delays.

Conclusions drawn by the study include the following:

- The expected cost and risk to the public (i.e., accident-related costs) at all design levels are very low. Hot cells within the waste handling building must meet stringent radiation-shielding requirements and thus have an inherently rugged design; even at the 0.2g design level, the risk to the public and the accident-related costs are both very small compared with the costs not related to accidents. This means that the repository surface facilities are low seismic-risk facilities.

- The total non-accident related cost is fairly constant for design levels between 0.2g and 0.6g.

- The increase in nonaccident-related costs if the design level is changed from the 0.4g to 1.0g is on the order of $150 million. The corresponding decrease in accident-related costs is on the order of $2,000.

- The current design for WHB-2 [Waste-handling building #2] has been evaluated for possible effect of fault displacement directly beneath the facilities. The WHB-2 appears quite resistant to potential fault displacement.

The report concludes that the optimum design level from a cost-benefit viewpoint would be between 0.24g and 0.53g. Choosing a design basis below 0.2g would probably entail programmatic delays in convincing the NRC of the adequacy of the design. Progressively higher design bases above 0.3g do not measurably reduce the risk to the public. Programmatic delays were not quantitatively included in the study.

Summary of New Information

Considerable work has been performed since publication of the EA that is relevant to this evaluation. This work, just reviewed, focuses on three areas: (1) ages of the Quaternary deposits in the Yucca Mountain area, (2) advances in methodologies for seismic hazard analysis, particularly in probabilistic and composite deterministic-probabilistic assessments, and (3) seismic design basis for the repository.

Improved estimates of the offset timing and rate of seismic activity depends on accurate dating of displaced stratigraphic and geomorphic features. Although some trenches and soil pits do exist in the Yucca Mountain area, additional strategically placed excavations are expected to be useful for refining the Quaternary stratigraphy and evaluating the amounts of offsets of units related to fault movement.

Various seismic-hazard analyses, both deterministic and probabilistic, have been performed at Yucca Mountain. The probabilistic analyses have been parametric because of lack of extensive data specific to Yucca Mountain. These and similar analyses can be used to represent seismic hazards and attain issue closure.

Preliminary seismic design studies of the effect of ground motion and surface rupture on the surface facilities, particularly the critical waste handling building, show that these structures are quite rugged and robust. As discussed by Subramanian et al. (1989), many factors must be included in the design. Confirmatory geological data may still be needed to validate the assumptions that went into the damage estimates for these facilities.

3.3.3.4.4 Current Status of Preclosure Tectonics Technical Issues

Technical Issue 1: Ground Motion

Seismic-response studies have been performed for existing critical facilities throughout the world and for planned facilities at Yucca Mountain. In general, more studies are found for surface facilities than underground structures. Extensive references exist for seismic-response studies of nuclear power plants and other critical facilities. Studies directly applicable to Yucca Mountain include, but are not limited to, DOE (1986, 1988a, 1990b); Jackson et al. (1985); Kiciman and Abrahamson (1989); Manning et al. (1990); Owen et al. (1980); Phillips and Luke (1991); Raney (1988a,b); Subramanian (1989); and Subrmanian et al. (1989).

This report does not attempt to synthesize all these studies but relies heavily on the work of Subramanian et al. (1989) for the design characteristics and responses of the surface facilities. The hazard for seismically induced damage to underground facilities is thought to be less than for the surface facilities during the preclosure period. The reader may consult the reference list (Section 5.0) for publications on the seismic-response characteristics of underground facilities at Yucca Mountain and elsewhere.

On the basis of Subramanian et al. (1989), the optimum design level for the waste handling building is between 0.24g and 0.53g. These authors estimate the probability of failure for a given PGA, assuming different design levels in the form of fragility curves such as Figure 3-4, which is for a 0.4g design level. The report states that for the light damage state, narrow cracks form but do not result in an opening for radioactive material to escape. For progressively higher damage states, wider cracks and concrete projectiles, caused by spalling of material from the walls of the WHB, become more numerous and result in a higher risk of potential release of radionuclides to the environment. Table 3-5 presents the estimated radioactive material released into the hot cell for the different damage states. This radioactive material released into the hot cell must also find a conduit to the outside of the hot cell to reach the environment. A cut-off acceleration of 2.5g is assumed in the Subramanian report, which is greater than the largest ground acceleration recorded anywhere in the world. Although the fragility curves are presented up to 20g, only those portions of the curves to the left of the cut-off acceleration are geologically plausible.

Figure 3-4 shows less than a 10^{-3} probability of light damage for a 0.5g PGA. Again, although this damage state would produce cracks in the walls of the waste handling building, no opening to the environment would result. A ground acceleration of greater than 1.0g is required to raise the probability of failure above 10^{-3} for moderate and higher damage states.

Numerous studies exist that estimate the expected ground motions at Yucca Mountain. These include, but are not limited to, King et al. (1989); Manning et al. (1990); Perkins et al. (1986); Phillips et al. (1991); Rogers et al. (1976, 1977, 1983, 1987a); SAIC (1985); Subramanian et al. (1989); Tarr and Rogers (1986); and URS/Blume (1986, 1987). Other references cited in the text of Subramanian et al. (1989) refer to more regional assessments of expected ground motion [e.g., Algermissen et al. (1982); Bonilla et al. (1984); dePolo et al. (1990); DOE (1986, 1988a); Greensfelder et al. (1980); Joyner and Boore (1988); and Thenhaus and Wheeler (1989)].

Studies at Yucca Mountain have been largely parametric, because of the lack of site-specific data. No attempt is made here to synthesize all previous work on expected ground motion at Yucca Mountain. Of the cited studies, the comprehensive studies by URS/Blume (1986, 1987) are chosen to evaluate Issue 1. Additional calculations of expected ground motion may be needed as new data is acquired or analysis techniques change.

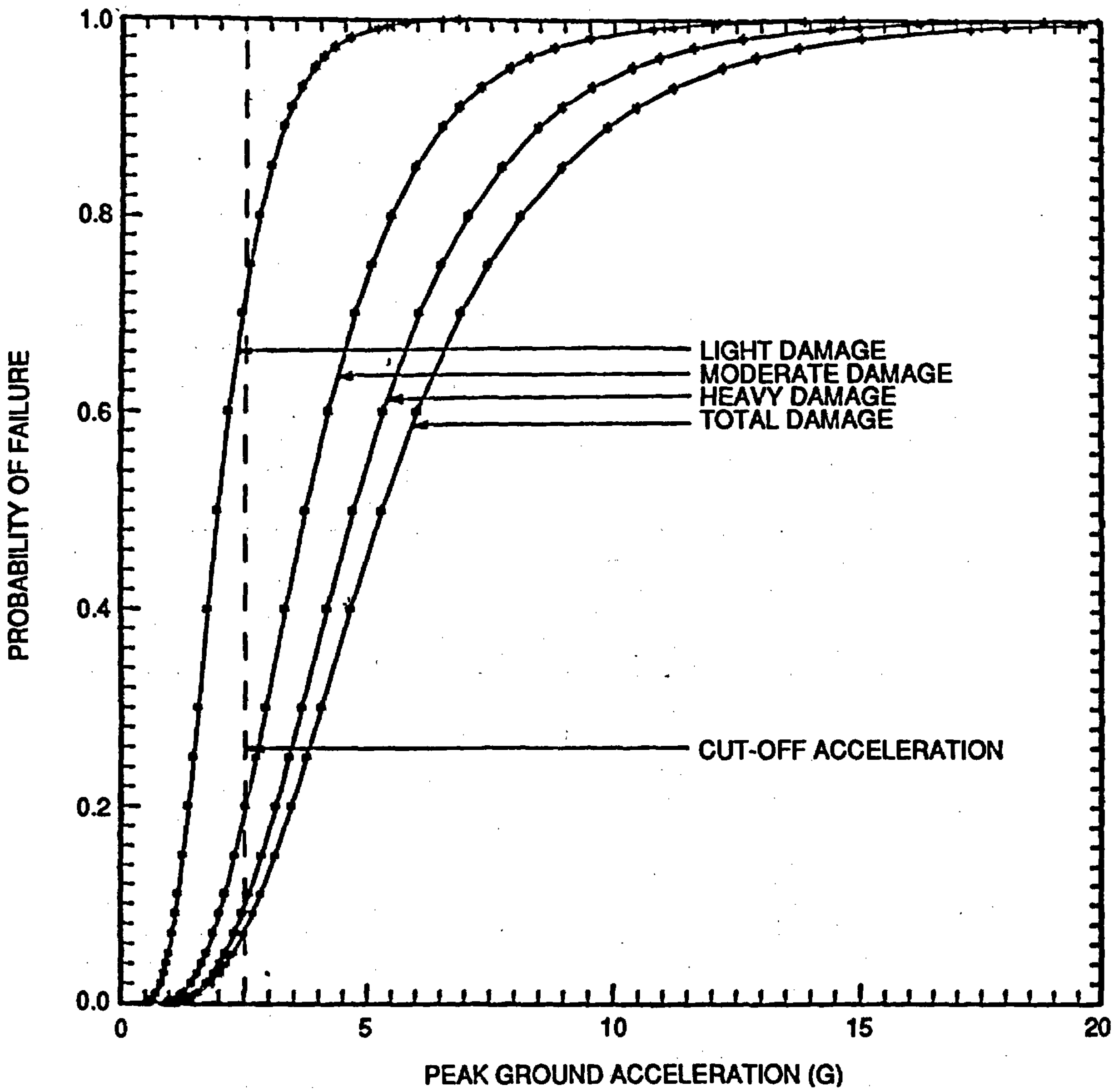


Figure 3-4. Fragility curve for the average wall of the Waste Handling Building, 0.4 g Design Basis (from Subramanian et al., 1989).

Table 3-5. Quantities of Radioactive Material Released into the Unloading Hot Cell for Four Damage States (Table 8-3 of Subramanian et al. [1989])

	Radiological Release (Ci)	
Damage State	Kr-85	Airborne Particulates
Light	0	0
Moderate	1.3×10^3	6.6×10^{-1}
Heavy	1.4×10^4	1.3×10^1
Total	7.7×10^4	1.2×10^2

Figure 3-5 shows results obtained by URS/Blume (1986), using a peak horizontal ground acceleration geometric deviation of 1.5, as determined by Campbell (1982), while Figure 3-6 presents PGA with geometric standard deviation of 1.9, as determined by Joyner and Boore (1982). A value of 1.5 for the geometric deviation is similar to the site-specific coefficient of variation observed at Yucca Mountain for Pahute Mesa UNE events, but is not considered appropriate by URS/Blume (1986) for earthquake hazard analysis in the absence of site-specific information at Yucca Mountain. These authors feel that a PGA geometric standard deviation of 1.9 is more appropriate for hazard estimation in the absence of site-specific information on earthquake ground motion at Yucca Mountain. Figure 3-7 presents a horizontal PGA for the Yucca Mountain site as recalculated by Subramanian et al. (1989).

Extrapolating the PGA curve for a 100-year recurrence expectancy, the expected lifetime of the surface facilities, a PGA of less than 0.2g would be expected. From the fragility curve in Figure 3-4, even a light damage state is extremely unlikely for this PGA. For a recurrence expectancy of 10,000 years in Figure 3-6, the largest expected PGA is about 0.6g, a value where a "light damage" level has a very small probability. Virtually no damage to "light damage," in the worst case, is expected during the next 100 years for a waste handling building facility (see also Lee et al., 1991) because of its inherent robustness.

URS/Blume (1986) present response spectra with recurrence expectancies, at all frequencies, of 500, 2000, and 10,000 years as shown in Figure 3-8. These uniform-hazard spectra are computed using the Joyner and Boore (1982) regression equations. Response spectra are defined for 12 periods in the band of 0.1 to 4.0 seconds and for 5 percent critical damping. For periods less than 0.1 second, a linear relationship is assumed between 0.1 second and the value determined by the peak acceleration at a nominal period of 0.025 second.

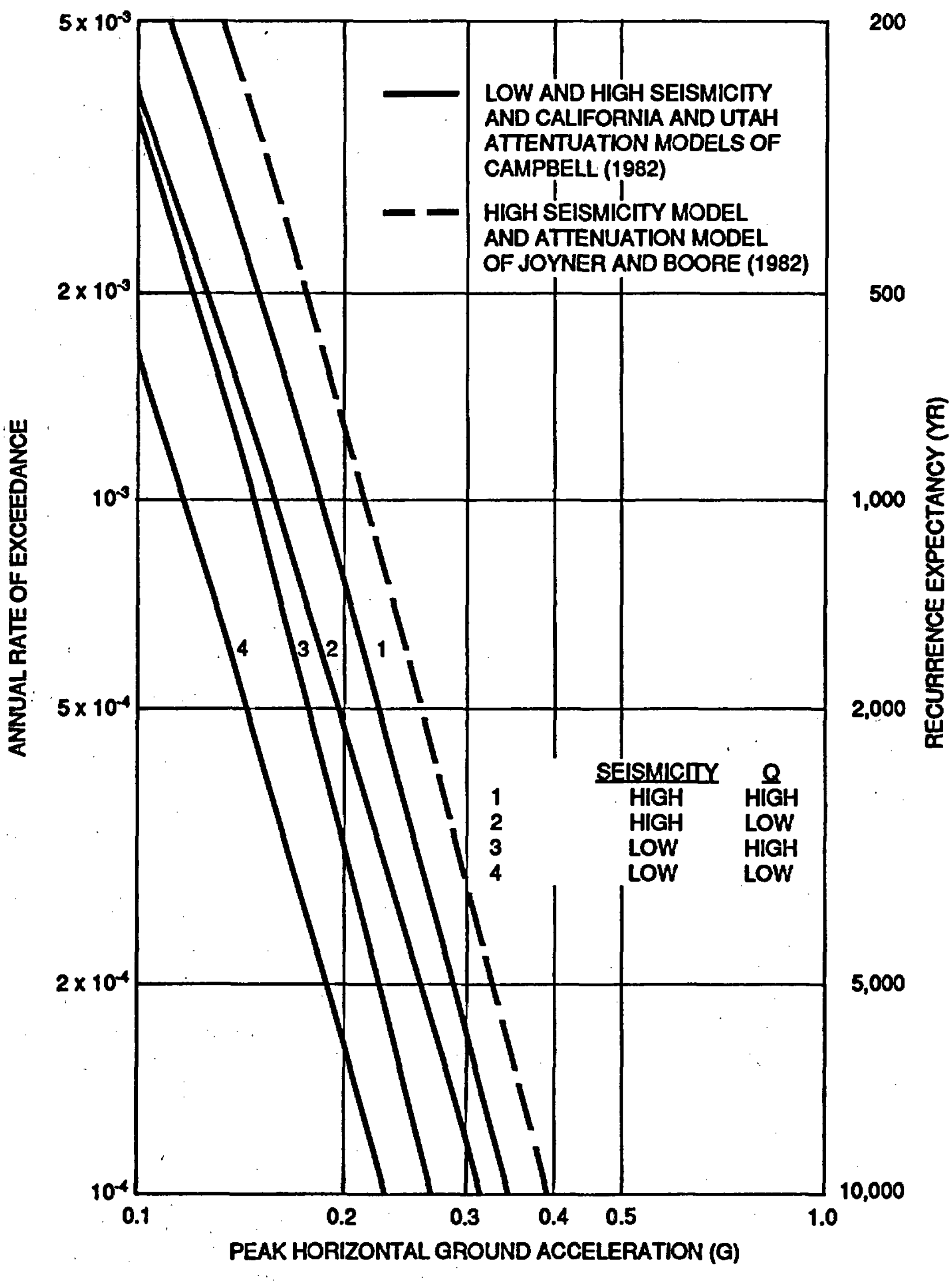


Figure 3-5. Earthquake hazard results for peak horizontal ground acceleration evaluated with a geometric standard deviation of 1.5 (from URS/Blume, 1986).

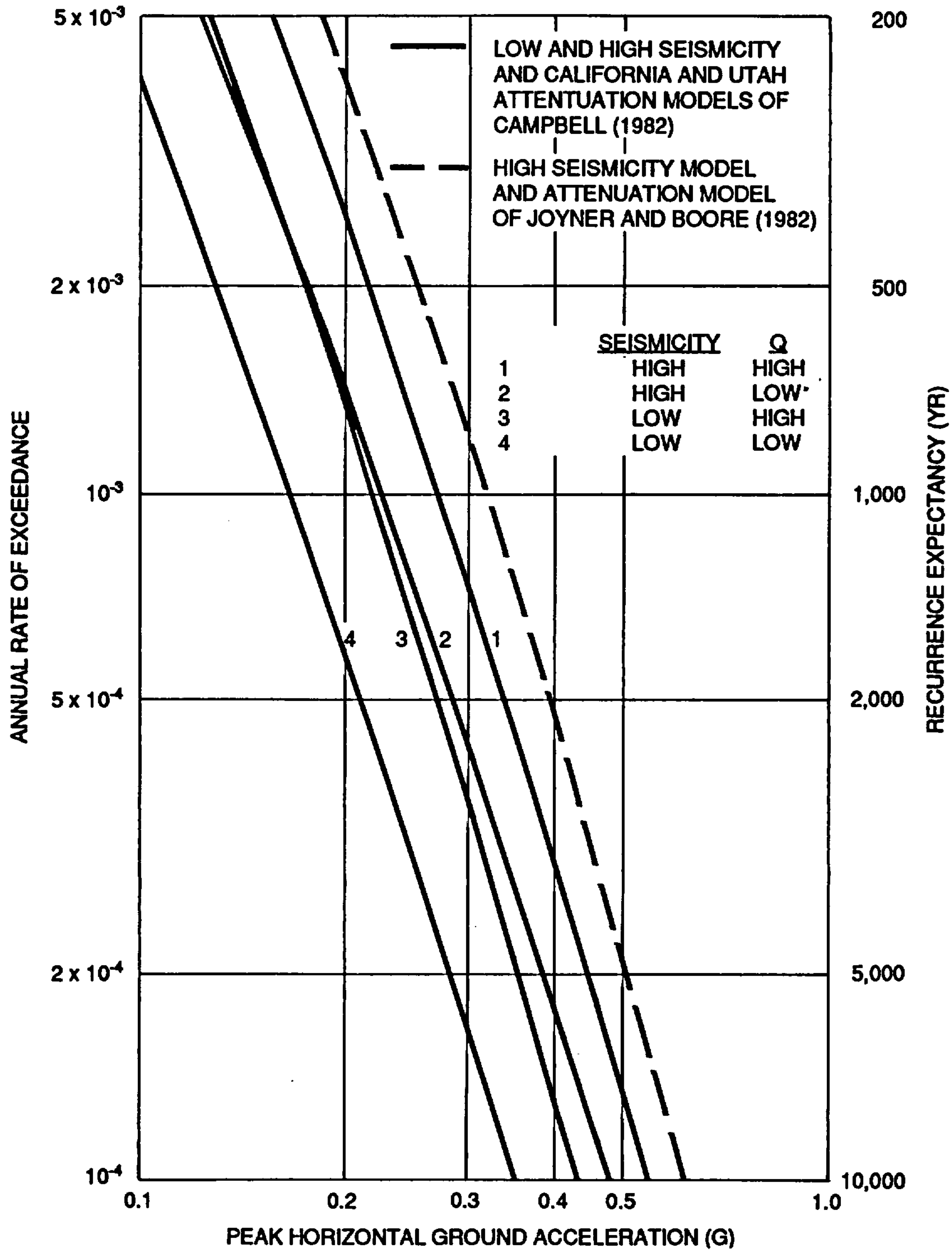


Figure 3-6. Earthquake hazard results for peak horizontal ground acceleration evaluated with a geometric standard deviation of 1.9 (from URS/Blume, 1986).

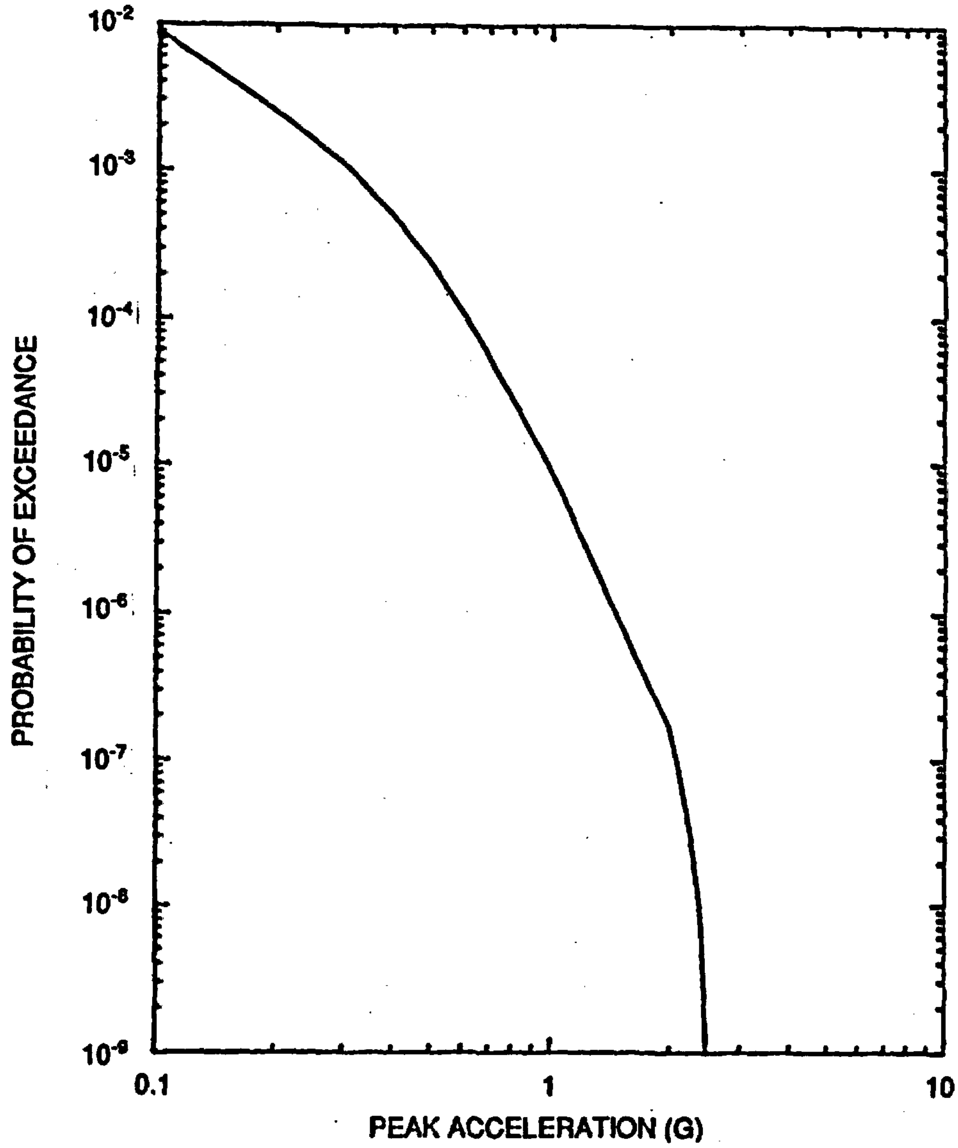
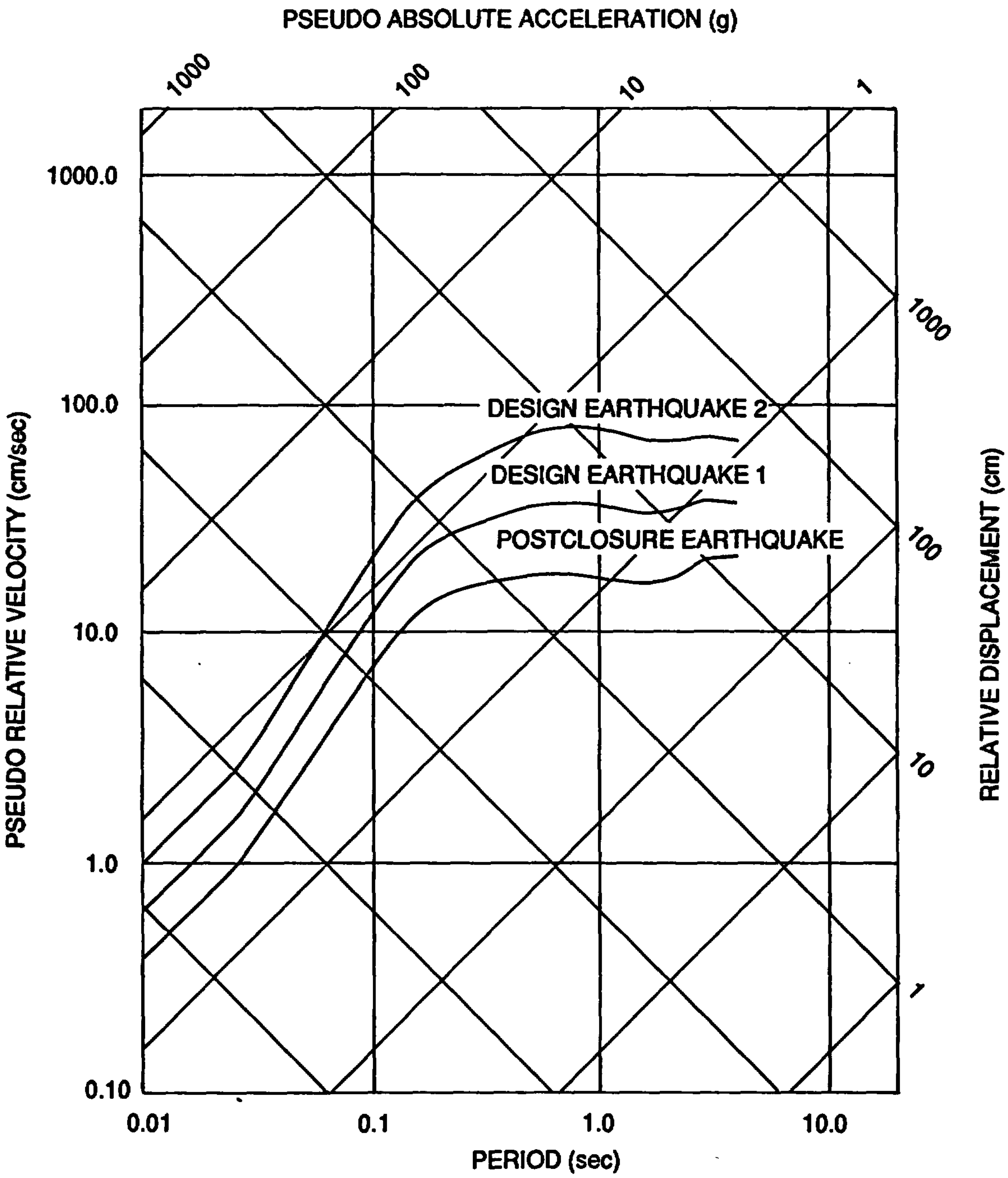


Figure 3-7. Recalculated horizontal ground acceleration seismic hazard curve for the Yucca Mountain Site (from Subramanian et al., 1989).



	RECURRENCE EXPECTANCY (year)	HORIZONTAL PGA (g)	VERTICAL PGA (g)
DESIGN EARTHQUAKE 2	500	0.25	0.17
DESIGN EARTHQUAKE 1	2,000	0.40	0.27
POSTCLOSURE EARTHQUAKE	10,000	0.65	0.65

Figure 3-8. Five percent-damped uniform-hazard response spectra for rock sites, horizontal component, for recurrence rates of 500, 2,000, and 10,000 years (from URS/Blume, 1986).

URS/Blume (1987) focuses on the sensitivity of seismic hazard to various earthquake magnitude recurrence and fault behavior parameters. The authors differentiate the contribution by certain faults and families of faults to the total seismic hazard. The calculated ground motion is dominated by the behavior of the Paintbrush Canyon fault and associated nearby faults and by background seismicity. Of the various input parameters considered in the study, the seismic hazard is most sensitive to an assumed slip-rate; however, few Quaternary slip-rates were available at the time of these calculations.

Alternative seismotectonic interpretations were parameterized by considering only normal faulting in one case and oblique-slip in the other. Recent work, including that by Whitney and Muhs (1991), supports oblique-slip on at least the Paintbrush Canyon-Stagecoach fault system. Preliminary evaluation of three alternative tectonic models. Oblique-slip, detachment, and shear was also made by URS/Blume (1987). Of these simplistic tectonic models, the shear model produced the greatest hazard while the detachment presented the least hazard. These models will presumably be refined as study continues.

Combining the fragility and ground motion hazard estimates for the surface facilities, the annual probability of exceeding a moderate damage state from ground motion is approximately 5×10^{-8} (Subramanian et al., 1989), approximately two orders of magnitude greater than the similar probability from surface-rupture hazards, as described in Technical Issue 2.

Unless new information contradicts the assumptions made in these analyses, the overall conclusions of the studies appear sound, and this issue is considered resolved. The analyses presented to resolve this issue, however, are still general and they may need to be validated by further site data collection to support a higher-level finding for the qualifying condition.

Technical Issue 2: Surface Displacement

Surface rupture studies have been performed for existing critical facilities throughout the world and for planned facilities at the Yucca Mountain site. Most critical facilities are located to avoid the hazard of surface fault displacement. Numerous facilities that are sited above surface fault ruptures are documented in the literature. Studies directly applicable to Yucca Mountain include, but are not limited to, DOE (1986, 1988a, 1990b); Jackson et al. (1985); Kiciman and Abrahamson (1989); Owen et al. (1980); Subramanian (1989), Subramanian et al. (1989); and URS/Blume (1986, 1987). This report does not attempt to synthesize all these studies but relies heavily on the work of Subramanian et al. (1989) for the design characteristics and responses of the surface facilities. The work by Subramanian et al. (1989) is the most recent comprehensive study directly addressing the response of the proposed repository surface facilities to seismic hazard.

The approach used by Subramanian et al. (1989) to estimate surface displacement hazards is similar to that used for ground-motion hazards. Figure 3-9 presents fault displacement fragility curves for a tilted

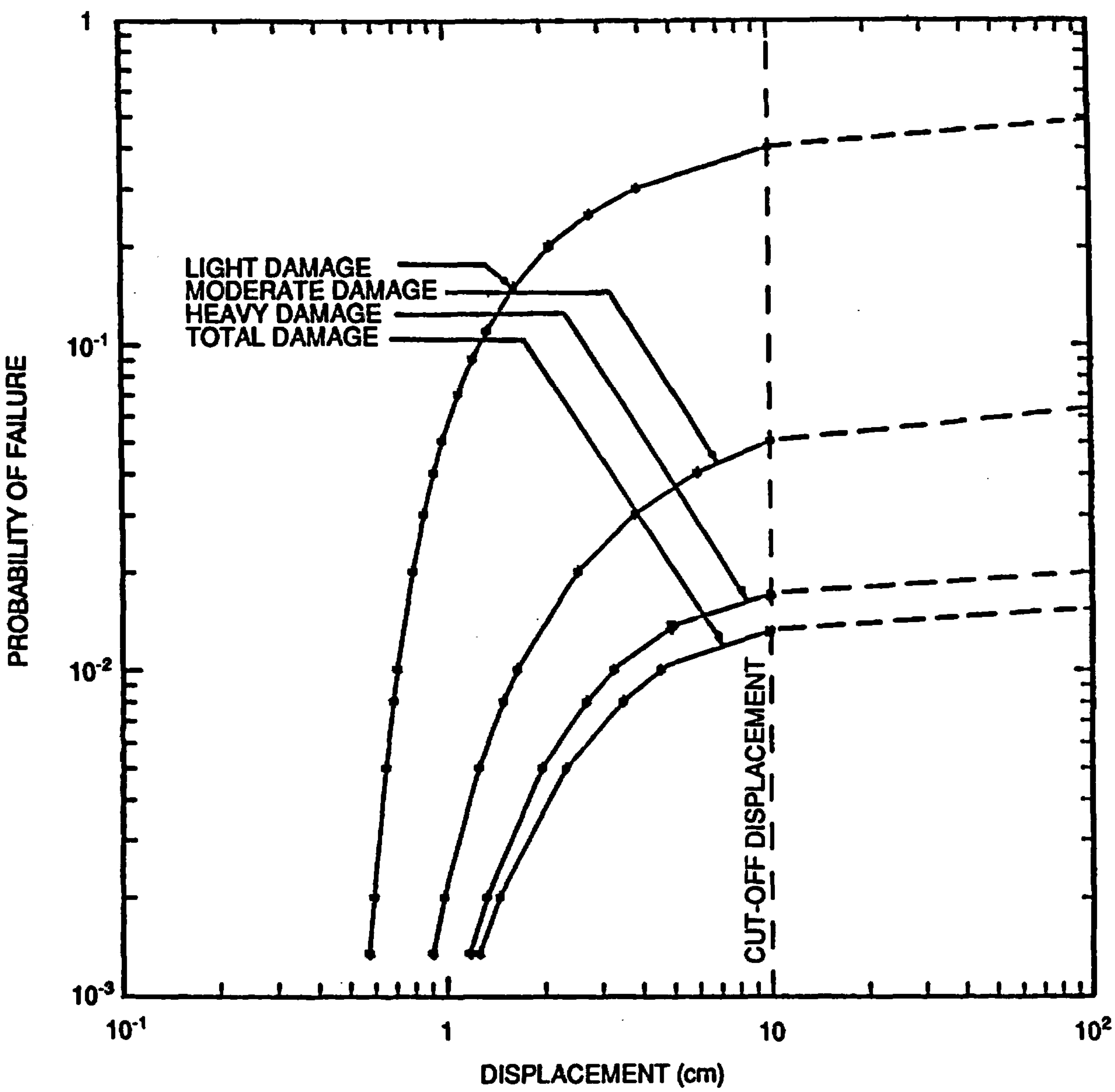


Figure 3-9. Fault displacement fragility curves for the Tilted Building Mode (of the Waste Handling Building), 0.4 g Design Basis (from Subramanian et al., 1989).

building mode, assuming a 0.4g design level. Similar fragility curves are provided for other ground-motion design levels. The probability of exceeding a moderate damage state, one involving potential release of radionuclides, is 2×10^{-3} and 5×10^{-2} for surface displacements of 1 and 10 cm, respectively.

According to Subramanian et al. (1989), an upper bound of 10 cm displacement represents the appropriate value below which fragilities could be meaningfully estimated; it does not represent an upper bound of geologically plausible fault displacements at Yucca Mountain. Faults known to be capable of producing 10 cm or more surface displacements are expected to be avoided in the siting of the surface facilities.

Numerous studies exist that provide data for and/or estimate the expected surface displacements at or near the proposed Yucca Mountain site. These include, but are not limited to, DOE (1986, 1988a, 1990b); Hildenbrand et al. (1988); King et al. (1989); Neal (1986); Stock et al. (1985); Subramanian et al. (1989); Swadley et al. (1984); Taylor (1986); Throckmorton (1987); URS/Blume (1987); Wesling et al. (in preparation); and Whitney et al. (1986). Other references cited in the text of Subramanian et al. (1989) refer to more regional assessments of expected surface displacement (e.g., Bonilla (1988); Bonilla et al. (1984); dePolo et al. (1990); Greensfelder et al. (1980); Joyner and Boore (1988); Ryall and VanWormer (1980); and Youngs et al. (1988)).

As with Technical Issue 1, no attempt is made here to synthesize all previous work on expected surface displacement at Yucca Mountain. Of the cited studies, the one by Subramanian et al. (1989) was chosen to evaluate Technical Issue 2.

Figure 3-10, from Subramanian et al. (1989), shows the estimated ground-rupture hazard for the Yucca Mountain site in an area in which the trenching program identifies no faulted stratigraphy. Probabilities of exceedance range from 10^{-7} for a vertical rupture of 1.0 cm to less than 10^{-12} for a vertical rupture of 100 cm (1 m.). Differential horizontal movement poses a lesser threat to the facilities since that movement would result in a rotation of the structure around a vertical axis as opposed to tilting of the foundations. In reality, the foundation would likely cantilever until it tilted enough to be touching the surface on the downthrown side of the fault. Effects are reduced by designing the foundations to accommodate small surface displacements.

Associated with ground rupture directly beneath the foundations of the waste handling building is a peak acceleration (Figure 3-11). Median accelerations were estimated deterministically with a zero distance from source to site. Peak acceleration remains more or less constant over a wide range of ground displacements according to the figure. Hazards from both surface rupture and ground motion must be combined for situations where the foundations of the surface facilities are faulted. Combining the fragility and fault displacement hazard estimates for the surface facilities, the probability of exceeding a moderate damage state from surface rupture, one for which there could be release of radionuclides, is approximately 4×10^{-10} (Subramanian, 1989), which is approximately two orders of magnitude less than the similar probability from ground-motion hazards (see Technical Issue 1).

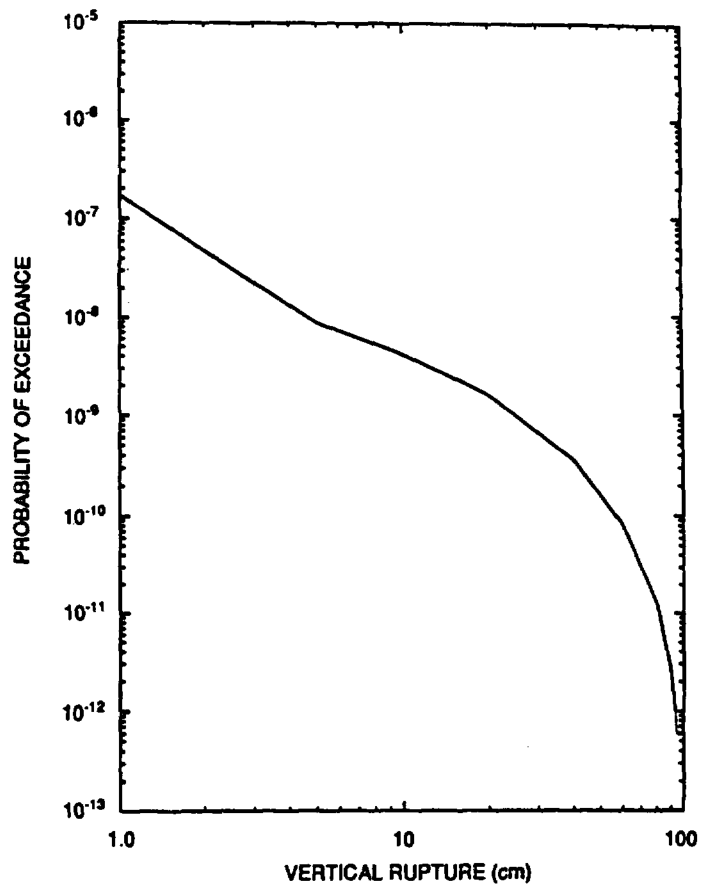


Figure 3-10. Ground rupture hazard curve for the Yucca Mountain Site (from Subramanian, 1989).

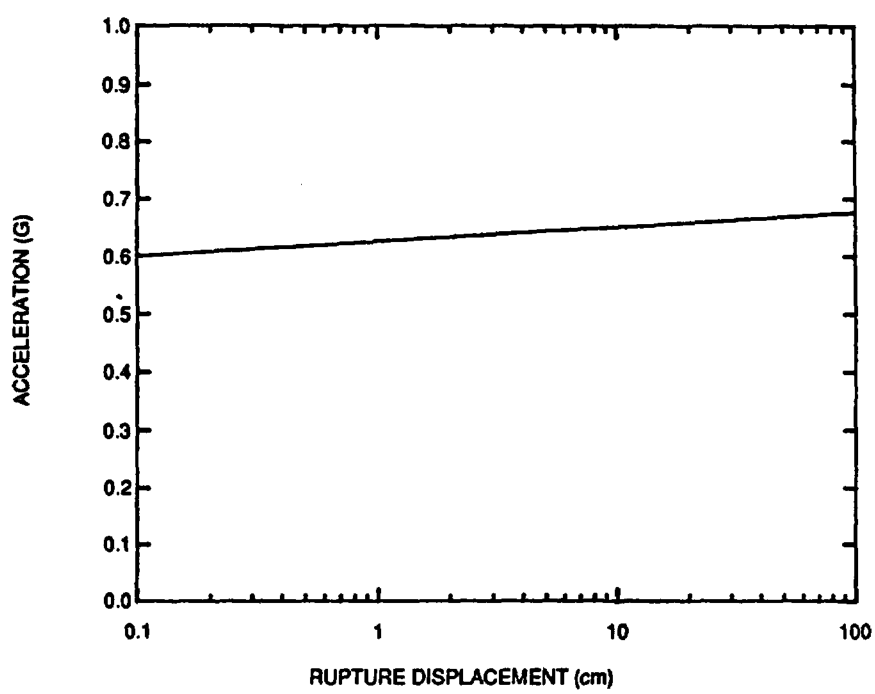


Figure 3-11. Median acceleration associated with ground rupture at the Yucca Mountain Site (from Subramanian et al., 1989).

Unless new information contradicts the assumptions made in these analyses, the overall conclusions of the studies appear sound. The analyses related to this issue, however, are still general and may need to be validated by further site data collection to support a higher-level finding for the qualifying condition.

Technical Issue 3: Seismic-Induced Surface Failure

The hazard from secondary, seismically induced geologic processes such as liquefaction, slope instability and failure, soil compaction, ground subsidence, and ground collapse, is generally small because of the small combined probability resulting from the seismic initiating event followed by the secondary event at the proposed repository site. Repository facilities will be designed for credible disruptive events, such as floods and fires (DOE, 1990a). Secondary seismically induced hazards would be included in this design analysis. Because of the expected soil strength (Ho et al., 1986) and low water content of soils throughout the Yucca Mountain area, liquefaction resulting from tectonic activity does not pose a hazard. The final location of ramp portals has not been determined, and may be on steep, bedrock- and colluvium-covered slopes. Although seismically induced slope failures could occur near the portal, with RAT and proper design and construction, these hazards can be mitigated. Proper location and design is also expected to mitigate the hazard from seismically induced slope failure on the tuff piles that result from excavation of the underground facility.

Other low probability events related to landslides or surface movement are described in other references. Fernandez et al. (1988) consider the somewhat more complicated scenario of movement of earth materials that causes retention of waters related to a maximum possible flood. In this scenario, the retained water would enter the repository through the Exploratory Studies Facility or other man-made access. They also report locations where slide blocks have been identified within the Yucca Mountain area. These rock slumps occur on slopes of 25 degrees or more and are usually of small volume. If surface facilities are not in areas of slopes greater than 25 degrees, rock slumps should not represent a threat.

Technical Issue 4: Volcanic Hazard

Perry and Crowe reviewed the hazards of volcanism during the preclosure period (Crowe, 1991b). They noted that there are two potential hazards. These are the vent zones associated with and surface deposits produced by nearby basaltic volcanic centers and ashfall from silicic eruptions in the western Great Basin. They used probability data from Crowe et al. (1982), but modified the disruption ratio to account for the area of surface effects of basaltic eruptions. Perry and Crowe calculated a probability of 3×10^{-5} for disruption of the repository by basaltic volcanism during a preclosure period of 100 years (Crowe, 1991b). They further suggested that the most likely volcanic effects during the preclosure period would be ashfall from a silicic eruption in either the Coso or the Long Valley area on the western margin of the Great Basin. On the basis of the volcanic history of these areas, an eruption during the preclosure period would most likely involve only a small volume ($<1\ km^3$) of erupted material and would deposit no more than 1 cm of ash on the Yucca Mountain site. Barring any unexpected information from site characterization studies, this hazard is considered to be properly bound.

3.3.3.4.5 Conclusions and Recommendation for Future Preclosure Tectonics Activities

Although the qualifying and disqualifying conditions for this guideline have very similar wording, Part IV (A) of the Background Information for 10 CFR 960 indicates that more extensive site characterization data may be needed, in some cases, to determine if a qualifying condition is present at a potential repository. In general, disqualifying conditions were intended to represent site features and conditions that could be evaluated earlier in the siting process. This is the basis on which the team conducting this evaluation has reached different findings for the qualifying and disqualifying conditions.

Qualifying Condition: The consensus of the Core Team is that current evidence continues to support the lower-level suitability finding (Level 3) for this qualifying condition. Additional site-specific seismic data are needed to reach an adequate level of confidence that the surface facilities can be designed to accommodate seismic hazards on the basis of RAT.

Disqualifying Condition: The consensus of the Core Team is that tectonic hazards can generally be accommodated using RAT, and new information is considered unlikely to change this conclusion. Therefore, a higher-level suitability finding is supported for this condition.

3.3.3.5 EVALUATION OF THE SYSTEM GUIDELINE QUALIFYING CONDITION FOR EASE AND COST OF SITING, CONSTRUCTION, OPERATION, AND CLOSURE

Qualifying Condition [10 CFR 960.5-1(a)(3)]: "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." [10 CFR 960.5-1(a)(3)]

Discussion

The Environmental Assessment (DOE, 1986) concluded that the siting, construction, operation, and closure of a repository at the Yucca Mountain site are not likely to require special technology and are considered to be feasible on the basis of existing technology (lower-level suitability finding). The consensus of the Core Team is that information obtained since that time continues to support this conclusion.

Summary of Findings for Technical and System Guidelines

Disqualifying Conditions: The consensus of the Core Team is that higher-level suitability findings are supported by the available information for the disqualifying conditions for the Preclosure Rock Characteristics, Hydrology, and Tectonics Technical Guidelines. An issue with regard to potential effects of mordenite during exploration of the Calico Hills unit was identified, but reasonable means exist to mitigate such effects. A number of issues were raised associated with the ability to construct facilities in the face of risks from potential seismic and fault displacement effects. The team concluded that these risks could be mitigated with reasonably available technology and that a higher-level suitability finding could be supported.

Qualifying Conditions: Evaluations of the qualifying conditions for Preclosure Surface Characteristics and Hydrology indicated no site features or conditions that could not easily be accommodated by RAT. Surface terrain is not extreme, if perched ground water is encountered during construction it is not expected to be difficult to control, and standard engineering design and control measures should mitigate flooding hazards. Therefore, it is the consensus of the Core Team that higher-level suitability findings can be supported for the Surface Characteristics and Hydrology qualifying conditions (Level 4).

Discussion:

For Preclosure Rock Characteristics, the consensus of the Core Team is that current evidence continues to support the lower-level suitability finding for the qualifying condition. An uncertainty remains as to whether there is sufficient contingency in lateral extent and thickness of the host rock to accommodate the repository facility. Discovery of features at the site that would reduce the estimates of competent rock available, or decisions to reduce the areal thermal loading, could lead to a situation where the currently preferred host rock could not adequately accommodate the underground facility. The consensus of the Core Team is that the likelihood for such a possibility is small; nevertheless, the team felt that additional information from the underground exploration program could indicate that such a condition exists, and a higher-level suitability finding could not be supported at this time.

For Preclosure Tectonics, the consensus of the Core Team is that current evidence continues to support the lower-level suitability finding for the qualifying condition. Although current evidence indicates that seismic and volcanic hazards at the Yucca Mountain site can be accommodated by RAT, additional site-specific data are needed to confirm that estimates of the seismic hazard potential are valid. Evidence that locations with the potential for surface displacement can be avoided or that minor low-probability displacements can be accommodated is needed together with improved estimates of the expected earthquake ground motion.

Report of Early Site Suitability Evaluation of the Potential Repository Site at Yucca Mountain, Nevada

SECTION 4: SUMMARY AND RECOMMENDATIONS

January 1992

4.0 SUMMARY AND RECOMMENDATIONS

4.1 SUMMARY OF THE ENVIRONMENTAL ASSESSMENT EVALUATION

The findings reported in the Environmental Assessment (EA) (U.S. Department of Energy [DOE], 1986) indicated that the site was suitable for characterization, based on information that was available at that time. Lower-level suitability findings were made on all of the qualifying and disqualifying conditions, except that higher-level suitability findings were made for the qualifying and disqualifying conditions for the Dissolution Guideline and two of three disqualifying conditions for the Population Density and Distribution Guideline. There were no unsuitability findings.

4.2 SUMMARY OF THE RESULTS OF THE PRESENT EARLY SITE SUITABILITY EVALUATION

Considerable data and analyses have been added to the information base for the Yucca Mountain site since the EA. This new information has been obtained from ongoing monitoring activities, field and laboratory studies, and reanalysis of information that was available before the EA using new analysis techniques. Although some issues remain unresolved, it is the consensus of the Core Team that the additional information corroborates the conclusion of the EA that the Yucca Mountain site is suitable for characterization. In some areas, the present evaluation supports findings stronger than those presented in the EA that the site is suitable for repository development.

Postclosure Guidelines

The Core Team concluded that current information does not support an unsuitability finding for any of the postclosure disqualifying or qualifying conditions. In other words, current information supports at least lower-level suitability findings for the disqualifying and qualifying conditions for all Postclosure Guidelines. Higher-level suitability findings can be supported for eight out of sixteen conditions. Table 4-1 summarizes the findings that can be supported for each Postclosure Guideline, and the following paragraphs summarize the basis for those results.

Disqualifying Conditions

Current evidence continues to support the lower-level suitability findings reported in the EA that no disqualifying conditions are present or are likely to be present at the Yucca Mountain site. The Core Team further concluded that additional information is unlikely to change these suitability findings except, possibly, the finding for the disqualifying condition in the Postclosure Geohydrology Technical Guideline. Consequently, with the exception of the Geohydrology Guideline, higher-level suitability findings are supported for all of the postclosure disqualifying conditions. The Postclosure Geohydrology disqualifying condition requires that the expected time of travel of ground water to a distance 5 km from the repository be not less than 1,000 years for any flow path along which radionuclide transport is likely to be significant. Present site information does not preclude the possible presence of flow pathways at the site in which ground-water flow

Table 4-1. Summary of Postclosure Guideline Evaluation Results[a,b]

Guideline	Disqualifying Condition	Qualifying Condition
System	Not applicable[c]	Condition is likely to be met (LLF)[d]
Technical		
Geohydrology	Condition is not likely to be present (LLF)	Condition is likely to be met (LLF)
Geochemistry	Not applicable	Condition is likely to be met (LLF)
Rock Characteristics	Not applicable	Condition is likely to be met (LLF)
Climatic Changes	Not applicable	Condition is likely to be met (LLF)
Erosion	Condition is not present and future information is unlikely to change conclusion (HLF)[e]	Condition is met and future information is unlikely to change conclusion (HLF)
Dissolution	Condition is not present and future information is unlikely to change conclusion (HLF)[f]	Condition is met and future information is unlikely to change conclusion (HLF)[f]
Tectonics	Condition is not present and future information is unlikely to change conclusion (HLF)	Condition is likely to be met (LLF)
Human Interferance		
Natural Resources	Conditions 1 and 2 not present and future information is unlikely to change conclusion (HLF)	Condition is likely to be met (LLF)
Site Ownership and Control	Not applicable	Condition is met and future information is unlikely to change conclusion (HLF)

[a]The results presented here are supported by every member of the Core Team.
[b]See Table E-1 for descriptions of Postclosure Guideline.
[c]Not applicable: 10 CFR Part 960 provides no disqualifying condition associated with this guideline.
[d]LLF: Lower-level suitability finding is supported.
[e]HLF: Higher-level suitability finding is supported.
[f]The Environmental Assessment (DOE, 1986) reported a higher-level suitability finding on this guideline.

velocities could be sufficiently high that the expected travel time could be less than 1,000 years. Because of the uncertainties associated with the existance of these flow pathways and their effect on radionuclide transport, only a lower-level suitability finding is supported for this disqualifying condition.

The bases for supporting higher-level suitability findings for the other disqualifying conditions are as follows. For the Erosion Guideline, site conditions are expected to allow the underground facility to be placed at a depth of 200 m or more below land surface. For the Dissolution Guideline, the minerals composing the potential host rock and surrounding rock units are not expected to be subject to significant dissolution for 10,000 years after closure of the repository. For the Tectonics Guideline, scenarios where fault movement or ground motion in the underground facility could directly cause loss of waste isolation are considered to be extremely unlikely. For the first disqualifying condition under the Natural Resources Guideline, surface studies at the site, together with an extensive search of the records of previous resource exploration and extraction activities in the Yucca Mountain region, indicate that no significant pathways are likely to be present at the site. For the second disqualifying condition under the Natural Resources Guideline, no credible scenarios have been identified through which activities outside the controlled area could lead to inadvertent loss of waste isolation.

Qualifying Conditions. Table 4-1 indicates that at least lower-level suitability findings continue to be supported for all of the qualifying conditions for the Postclosure Technical Guidelines. Furthermore, the Core Team has high confidence that new information is unlikely to change the conclusion that the qualifying conditions will be satisfied for the Erosion, Dissolution, and Site Ownership and Control Technical Guidelines. Thus, higher-level suitability findings are supported for these latter three qualifying conditions.

The bases for supporting these higher-level findings are as follows. For the Erosion and Dissolution Guidelines, no credible scenarios were identified by which erosion or dissolution processes would be likely to lead to releases greater than those allowable in accordance with the Postclosure System Guideline. For the Site Ownership and Control Guideline, a process is available for land withdrawal by the U.S. Government, the DOE has been successful in obtaining access and rights for the site characterization phase of the program, and no impediments to complete ownership and control are expected.

System Guideline. The Core Team concluded that current information continues to support a lower-level suitability finding for the Postclosure System Guideline. Aqueous-phase releases of radionuclides to the accessible environment are expected to meet the EPA release limits by an appreciable margin. There are, however, significant issues and uncertainties remaining with regard to possible gaseous-phase carbon-14 releases to the accessible environment. These issues include uncertainties in the amount of carbon-14 available to be released as carbon dioxide gas from the waste package and in the ability of the unsaturated zone to retard gaseous-phase carbon-14 transport to the accessible environment above the repository. The potential health hazards in terms of doses to members of the public from releases of gaseous carbon-14 are expected to be negligible, however, and possibly reflect an inconsistency between the regulatory limits and the actual hazard.

Preclosure Guidelines

The Core Team concluded that current information does not support any unsuitability findings for the preclosure disqualifying or qualifying conditions. In other words, the information supports at least lower-level suitability findings for all disqualifying and qualifying conditions for the Preclosure Guidelines. In addition, the Core Team concluded that higher-level suitability findings can be supported for 10 of the total of 24 qualifying and disqualifying conditions. Table 4-2 lists the level of findings that can be supported for each Preclosure Guideline, and the following paragraphs summarize the bases for those findings.

Radiological Safety Guidelines. Table 4-2 indicates that higher-level suitability findings can be supported for seven of nine of the qualifying and disqualifying conditions for the Radiological Safety Guidelines. For the Population Density and Distribution, Site Ownership and Control, and Meteorology Guidelines, site conditions are not expected to cause constraints on repository design, and in fact, are favorable to the protection of workers and the public from radiological exposure. The preclosure repository system is composed of engineered systems, including equipment and process controls, that are similar to those used in established industrial practice. Thus, the engineering design process is expected to accommodate the issues raised under this set of guidelines, and no significant site-related suitability concerns have been identified. However, the absence of site-specific release calculations and details about facility designs preclude the team from supporting a higher-level suitability finding for the qualifying conditions for Offsite Installations and Operations and for the System Guideline for Radiological Safety at this time.

Environment, Socioeconomics, and Transportation Guidelines. For the Preclosure Guidelines covering Environmental Quality, Socioeconomic Impacts, and Transportation-related impacts, the consensus of the Core Team is that the lower-level findings supported in the EA for all qualifying and disqualifying conditions continue to be supported by current information. In particular, available evidence supports findings that no disqualifying conditions are present and that all qualifying conditions can be met.

In one case (the second disqualifying condition for the Environmental Quality Guideline), a higher-level suitability finding is supported. This condition specifies that no part of the restricted area or repository support facilities should be located in a protected area (e.g., a component of the National Park System, the National Wildlife Refuge System, National Wilderness Preservation System, or the National Wild and Scenic Rivers System). According to current DOE plans, none of the planned repository support facilities or the repository restricted area will be located within such land parcels, providing adequate support for the higher-level suitability finding on this disqualifying condition.

For the first and third Environmental Quality disqualifying conditions and the qualifying condition, the Core Team concluded that information is currently insufficient to determine the potential environmental impacts, the

Table 4-2. Summary of Preclosu[illegible]uideline Evaluation Results[a,b]

Guideline	Disqualifying Condition	Qualifying Condition
	PRECLOSURE RADIOLOGICAL SAFETY	
System	Not applicable[c]	Condition is likely to be met (LLF)[d]
Technical		
Population Density and Distribution	Conditions 1, 2, and 3 are not present and future information is unlikely to change conclusions (HLF)[e,f]	Condition is met and future information is unlikely to change conclusion (HLF)
Site Ownership and Control	Not applicable	Condition is met and future information is unlikely to change conclusion (HLF)
Meteorology	Not applicable	Condition is met and future information is unlikely to change conclusion (HLF)
Offsite Installations and Operations	Condition is not present and future information is unlikely to change conclusion (HLF)	Condition is likely to be met (LLF)
	ENVIRONMENTAL QUALITY - SOCIOECONOMIC IMPACTS - TRANSPORTATION	
System	Not applicable	Condition is likely to be met (LLF)[f]
Technical		
Environmental Quality	Conditions 1 and 3 are not likely to be present (LLF) Condition 2 is not present and future information is unlikely to change conclusion (HLF)	Condition is likely to be met (LLF)
Socioeconomic Impacts	Condition is not likely to be present (LLF)	Condition is likely to be met (LLF)
Transportation	Not applicable	Condition is likely to be met (LLF)

Table 4-2. Summary of Preclosure Guideline Evaluation Results[a,b] (continued)

Guideline	Disqualifying Condition	Qualifying Condition
EASE AND COST OF SITING, CONSTRUCTION, OPERATION, AND CLOSURE		
System	Not applicable	Condition is likely to be met (LLF)
Technical		
Surface Characteristics	Not applicable	Condition is met and future information is unlikely to change conclusion (HLF)
Rock Characteristics	Condition is not present and future information is unlikely to change conclusion (HLF)	Condition is likely to be met (LLF)
Hydrology	Condition is not present and future information is unlikely to change conclusion (HLF)	Condition is met and future information is unlikely to change conclusion (HLF)
Tectonics	Condition is not present and future information is unlikely to change conclusion (HLF)	Condition is likely to be met (LLF)

[a]The results presented here are supported by every member of the Core Team.
[b]See Table E-2 for descriptions of Preclosure Guideline.
[c]Not applicable: 10 CFR Part 960 provides no disqualifying condition associated with this guideline.
[d]LLF: Lower-level suitability finding is supported.
[e]HLF: Higher-level suitability finding is supported.
[f]Higher-level suitability findings on disqualifying conditions 1 and 2 are reported in the Environmental Assessment (DOE, 1986).

mitigation measures that may be needed, and the potential for irreconcilable conflicts with federally protected lands. However, available evidence suggests that potential impacts can be mitigated to an acceptable degree and that irreconcilable conflicts are not likely to occur.

For the Socioeconomic Impacts qualifying and disqualifying conditions, additional information is needed to gain the confidence needed to support higher-level suitability findings. Significant degradation of water quality or quantity that cannot be mitigated is not expected due to repository construction, operation, or closure, and water supplies in the area of the Yucca Mountain site are believed to be adequate for repository needs. According to the qualifying condition, a process of analysis, planning, and consultation among the DOE and affected parties should be used to determine the mitigation and compensation measures that are needed to avoid significant adverse social and/or economic impacts in communities and surrounding regions. Although the Core Team concluded that unmitigatable social and/or economic impacts are not expected, sufficient information is not yet available to support a higher-level suitability finding for this qualifying condition.

The qualifying condition for the Transportation Guideline requires that (1) irreconcilable conflicts be avoided between access routes and federally protected lands; (2) reasonably available technology can be used for design and construction; (3) no need exists for performance standards more stringent than those of the U.S. Department of Transportation and the U.S. Nuclear Regulatory Commission (NRC) or for the development of new packaging containment technology; and (4) no unacceptable risks to the public or unacceptable environmental impacts resulting from transportation operations exist. Although the Core Team concluded that available information indicates that this condition will be met for the Yucca Mountain site, additional information about potential risks to the public due to transportation, as well as information about potential environmental impacts and packaging technologies, is needed to support a higher-level suitability finding.

Ease and Cost of Siting, Construction, Operation, and Closure Guidelines. Table 4-2 shows a Core Team consensus that higher-level findings can be supported for all of the disqualifying conditions and for two of the qualifying conditions for this set of guidelines. In general, the higher-level findings are supported on the basis of confidence that the engineering, materials, and services necessary to conduct repository-related activities at Yucca Mountain are within reasonably available technology (RAT). Hazards due to surface topography, flooding, rock stability, seismic conditions, or ground-water problems in the underground facility are not expected to require engineering measures that have not been applied and proven elsewhere in similar facilities.

A question remains about the adequacy of the thickness and lateral extent of the proposed host rock to accommodate the underground repository facilities. Current evidence indicates potential constraints on the location of facilities and changes in the design basis for the allowable rates of heat generation by the emplaced waste could place additional demands on the amount of host rock needed. Thus, although available evidence continues to support a lower-level suitability finding for the qualifying condition for the

Preclosure Rock Characteristics Guideline, new information could change this conclusion.

Current evidence also continues to support the lower-level suitability finding for the qualifying condition for the Preclosure Tectonics Guideline. However, uncertainty exists about the ability to accommodate the seismic conditions at the site using reasonably available technology. Current information about the ground-motion or surface-rupture conditions is not sufficiently mature to serve as the design basis for repository facilities. Therefore, the higher-level suitability finding is not supported at this time.

Given that lower-level suitability findings are supported for the qualifying conditions for the Preclosure Rock Characteristics and Tectonics Guidelines, the Core Team concluded that only a lower-level suitability finding presently can be supported for the System Guideline for this group of guidelines.

4.3 RECOMMENDATION TO RESOLVE AND CLOSE ISSUES

The Core Team recommends two kinds of actions to resolve issues that are key to determining the suitability of the Yucca Mountain site. These actions involve (1) further investigation where more information is needed to support higher-level findings with respect to site suitability criteria and (2) formally "closing" some issues where additional information gathering is unlikely to change present conclusions regarding site suitability.

Resolve Issues. The Core Team recommends that the DOE conduct activities to resolve technical issues associated with the guidelines where only lower-level suitability findings presently can be supported. Tables 4-1 and 4-2 identify these guidelines, and the evaluations in Sections 2 and 3 provide specific recommendations to resolve these issues.

Perhaps the most important of these technical issues is the question of release of gaseous carbon-14 to the accessible environment. Section 2.4.3 explains there is considerable uncertainty in the source term being used to estimate releases and in the retardation that might occur in the repository overburden. The Core Team recommends that the DOE develop a strategy for dealing with this issue. For example, the DOE could consider actions to reduce these uncertainties by refining estimates of the inventory of carbon-14 in spent nuclear fuel and by investigating engineered-barrier designs that could mitigate possible releases of gaseous carbon-14. In addition, the DOE can continue its interactions with the EPA on revisions to 40 CFR Part 191, including the containment requirement for carbon-14. There may be reasons for reconsidering these limits, including (1) the EPA release limits for carbon-14 were established without explicitly considering possible gaseous releases; (2) preliminary analyses indicate that negligible public health risk is associated with a carbon-14 release equal to the EPA release limits, and (3) containment requirements for carbon-14 may not be consistent with other regulations, such as the Clean Air Act (CAA, 1990).

Document Resolution of Issues. The Core Team also recommends that steps be taken to document and close resolved issues associated with guidelines for which information supports higher-level suitability findings and where formal closure is appropriate. For example, closure may be appropriate for issues related to the Erosion and Preclosure Hydrology Guidelines where suitability issues are resolved and further testing with specific reference to these guidelines is not needed.

One method of closure would be for the DOE to adopt the evaluations of this report as formal suitability findings. Another might be to prepare position papers that document the basis for resolving issues, based either on the material presented in Sections 2 and 3 or on further evaluation by the DOE. A third approach is applicable to some of the resolved issues that are expected to be subjects of discussion between the DOE and the NRC as part of possible future license application activities. The DOE could develop position papers on these issues and have them reviewed by the NRC. The Site Characterization Plan proposes an approach that involves developing Issue Resolution Reports that would be submitted to the NRC for review and acceptance. The evaluations presented in Sections 2 and 3 of this report could provide the bases for developing these reports.

4.4 RECOMMENDATION TO PRIORITIZE THE TESTING PROGRAM

During this early site suitability evaluation, the Core Team identified areas in which additional site information is needed before higher-level findings can be supported. In some cases, studies were identified that could provide this information. However, this evaluation did not explicitly assess the site characterization activities that might be performed to obtain the needed information or the monetary costs of these activities relative to the value of information they could provide. Factors such as the availability and reliability of testing methods to obtain needed information should be taken into account in a comprehensive evaluation of site suitability as part of the determination of whether additional information gathering could change suitability conclusions. The cost and value of additional information are appropriate for the DOE to consider in making decisions about whether to continue site characterization, recommend the site for repository development, or abandon the site as unsuitable for repository development.

For example, in the evaluation of several technical guidelines, the Core Team concluded that the site is likely to be suitable, but that some important uncertainties still exist. In such cases, lower-level suitability findings were considered to be appropriate. However, further assessment may determine that the residual uncertainties may not be resolvable through any feasible site characterization activity. In this case, DOE decision makers might consider terminating site characterization and either abandon the site as unsuitable or recommend it for repository development. The decision would depend on the relative importance of the residual uncertainties and the consequences of abandoning the site. This is the type of decision represented by the diamond in Figure 1-1. Such decisions may be based on site suitability evaluation results, but these decisions may differ from the guideline findings because more factors may be taken into account.

The Test Prioritization Task (TPT) (Mattson et al., 1991) developed an approach for prioritizing site characterization activities that addressed some of these concerns. This approach was applied to a subset of the site characterization program, in particular to those tests intended for early detection of potentially unsuitable postclosure site conditions. The TPT explicitly assessed the importance of residual uncertainties, the availability of specific tests, and their reliability in resolving key uncertainties.

The TPT found that the importance of resolving various postclosure issues varies widely. There are instances where establishing the presence of a potentially unsuitable site condition could lead to predictions of measurable releases of radionuclides, and there are other instances where the establishing presence of a site condition has negligible influence on releases. When the accuracies of proposed tests are considered explicitly, there are instances where tests are not sufficiently accurate to detect an unlikely but potentially unsuitable site condition. In fact, in many of these cases, the tests are more likely to produce a false indication (i.e., false alarm) that the condition is present when, in fact, it is not.

An approach similar to that used on the TPT could be used to prioritize the testing needed to resolve the open site suitability issues. In instances where a higher-level suitability finding can be supported, it may be appropriate to limit or stop further testing designed to improve understanding of the relevant site conditions. However, there are many reasons for testing, and each of these should be considered when prioritizing site characterization activities. In particular, the approach should (1) address preclosure qualifying and disqualifying conditions, (2) analyze all of the technical issues identified in this report, and (3) consider explicitly other reasons for site characterization, such as information needed to build confidence, to prepare a license application, and to resolve design issues. Furthermore, the economic and false-alarm costs of proposed tests need to be balanced against their benefits in satisfying the above motivations for testing.

The Core Team recommends that a comprehensive prioritization effort be considered to identify and prioritize those site characterization activities whose results will bear directly on resolving open site suitability issues.

Report of Early Site Suitability Evaluation of the Potential Repository Site at Yucca Mountain, Nevada

SECTION 5: REFERENCES

January 1992

This reference list showing accession numbers for each cited reference will be issued separately as a supplement to this report.

5.0 REFERENCES

ANSI/ANS (American National Standards Institute/American Nuclear Society), 1981. American National Standard for Determining Design Basis Flooding at Power Reactor Sites, ANSI/ANS-2.8-1981, American Nuclear Society, La Grange Park, IL.

Abbott, E. W., E. B. Hodos, M. J. Johnson, and R. S. Friberg, 1989. Northern Nevada Section - AIPG 1989 Field Trip, March 19, 20, 21, 1989, Bullfrog Mine, Nevada Test Site, Cyprus Tonopah Mine, American Institute of Professional Geologists, Washington, DC.

Algermissen, S. T., D. M. Perkins, P. C. Thenhaus, S. L. Hanson and B. L. Bender, 1982. Probabilistic Estimates of Maximum Acceleration and Velocity in Rock in the Contiguous United States, USGS-OFR-82-1033, unpublished draft, Open-File Report, U.S. Geological Survey, 99 pp.

Allcott, G. H., 1991. Letter from G. H. Allcott (Chief Office of Mineral Resources) to T. V. Leshendok (Deputy State Director, Bureau of Land Management), January 8, 1991; regarding Meeting to Review Ratings of the Oil and Gas Potential of Wilderness Land in East-Central Nevada.

Apted, M. J., A. M. Liebetrau, and D. W. Engel, 1989. The Analytical Repository Source-Term (AREST) Model: Analysis of Spent Fuel as a Nuclear Waste Form, PNL-6347, Pacific Northwest Laboratory, Richland, WA.

Apted, M. J., W. J. O'Connell, K. H. Lee, A. T. MacIntyre, T.-S. Ueng, T. H. Pigford, and W. W.-L. Lee, 1991. Preliminary Calculations of Release Rates from Spent Fuel in a Tuff Repository, UCRL-JC-104832, preprint, Lawrence Livermore National Laboratory, Livermore, CA.

Ardila-Coulson, M. V., 1989. The Statewide Radioactive Materials Transportation Plan, Phase II, College of Engineering, University of Nevada, Reno.

Aronson, J. L., and D. L. Bish, 1987. Distribution, K/Ar Dates, and Origin of Illite/Smectite in Tuffs from Cores USW G-1 and G-2, Yucca Mountain, Nevada, a Potential High-Level Radioactive Waste Repository, 24th Annual Meeting Clay Minerals Society, Abstracts, Oct. 18-22, 1987, Socorro, NM, p. 25.

Arulmoli, K., and C. M. St. John, 1987. Analysis of Horizontal Waste Emplacement Boreholes of a Nuclear Waste Repository in Tuff, SAND86-7133, Sandia National Laboratories, Albuquerque, NM.

Aymard, W. H., 1989. Hydrocarbon Potential of Yucca Mountain, Nevada, unpublished Master's thesis, University of Nevada, Reno.

BLM (U.S. Bureau of Land Management), 1988. Right-of-Way Reservation, January 6, 1988, N-47748, 2800 (NV-943.2), Reno, NV.

BLM (U.S. Bureau of Land Management), 1989. Right-of-Way Reservation, October 10, 1989, N-48602, 2800 (NV-943.2), Reno, NV.

Ball, S. H., 1907. A Geologic Reconnaissance in Southwestern Nevada and Eastern California, U.S. Geological Survey Bulletin 308, U.S. Government Printing Office, Washington, DC, 218 pp.

Ballou, L. B., D. N. Montan, and M. A. Revelli, 1990. Spent Fuel Receipt Scenarios Study, UCID-21530, Lawrence Livermore National Laboratory, Livermore, CA.

Baris, I., L. Simontato, M. Artvinli, F. Pooley, R. Saracci, J. W. Skidmore, and J. C. Wagner, 1987. Epidemiological and Environmental Evidence of Health Effects of Exposure to Erionite Fibres: A Four-year Study in the Cappodocian Region of Turkey, International Journal of Cancer, Vol. 39, pp. 10-17.

Barnard, R. W., and H. A. Dockery (eds.), 1991a. Technical Summary of the Performance Assessment Calculational Exercises for 1990 (PACE-90), Volume 1: "Nominal Configuration" Hydrogeologic Parameters and Calculational Results, SAND90-2726, Sandia National Laboratories, Albuquerque, NM.

Barnard, R. W., and H. A. Dockery, 1991b. Internal memorandum from R.W. Barnard and H.A. Dockery to L. Shepard, June 11, 1991, Sandia National Laboratories, Albuquerque, NM; regarding fast path analyses for site suitability.

Barnes, M. W., and D. M. Roy, 1983. The Buffering Mechanisms in Leaching of Composites of Cement with Radioactive Waste, in Scientific Basis for Nuclear Waste Management VI, Materials Research Society Symposia Proceedings, November 1982 in Boston, Massachusetts, Vol. 15, North-Holland, NY, pp. 159-166.

Bates, J. K., W. L. Ebert, D. F. Fischer, and T. J. Gerding, 1988. The Reaction of Reference Commercial Nuclear Waste Glasses during Gamma Irradiation in a Saturated Tuff Environment, Journal Materials Research Society, Vol. 3, No.3, pp. 576-597.

Bath, G. D., and C. E. Jahren, 1984. Interpretations of Magnetic Anomalies at a Potential Repository Site Located in the Yucca Mountain Area, Nevada Test Site, USGS-OFR-84-120, Open-File Report, U.S. Geological Survey, 40 pp.

Bauer, S. J., and L. S. Costin, 1990. Thermal and Mechanical Codes First Benchmark Exercise Part II: Elastic Analysis, SAND89-0757, Sandia National Laboratories, Albuquerque, NM.

Bauer, S. J., L. S. Costin, E. P. Chen, and J. R. Tillerson, 1988. Thermal/Mechanical Analyses of G-Tunnel Field Experiments at Rainier Mesa, Nevada, SAND88-0453C, Sandia National Laboratories, Albuquerque, NM.

Bedinger, M. S., J. R. Harrill, and J. M. Thomas, 1984. Maps Showing Ground-Water Units and Withdrawal, Basin and Range Province, Nevada, Map USGS-WRI-83-4119-A, Scale 1:500,000, Water-Resources Investigations Report, U.S. Geological Survey.

Bedinger, M. S., K. A. Sargent, and W. H. Langer (eds.), 1989. Studies of Geology and Hydrology in the Basin and Range Province, Southwestern United States, for Isolation of High-Level Radioactive Waste-Characterization of the Death Valley Region, Nevada and California, U.S. Geological Survey Professional Paper 1370-F, U.S. Government Printing Office, Washington, DC.

Bell, E. J., and L. T. Larson, 1982. Overview of Energy and Mineral Resources for the Nevada Nuclear Waste Storage Investigations, Nevada Test Site, Nye County, Nevada, NVO-250, Nevada Operations Office, U.S. Department of Energy, Las Vegas, NV.

Bell, J. W., A. R. Ramelli, C. M. dePolo, and H. R. Bonham, Jr., 1988. Quaternary Geology and Active Faulting at and near Yucca Mountain, Task 1 Final Report, January 1, 1987-June 30, 1988, in Evaluation of the Geologic Relations and Seismotectonic Stability of the Yucca Mountain Area, Nevada Nuclear Waste Site Investigation (NNWSI). Center for Neotectonic Studies, Mackay School of Mines, University of Nevada, Reno.

Benson, L. V., and P. W. McKinley, 1985. Chemical Composition of Ground Water in the Yucca Mountain Area, Nevada, 1971-84, USGS-OFR-85-484, Open-File Report, U.S. Geological Survey, 10pp.

Benson, L. V., and R. S. Thompson, 1987. The Physical Record of Lakes in the Great Basin, Chapter 11, North America and Adjacent Oceans During the Last Deglaciation, The Geology of North America, W. F. Ruddiman and H. E. Wright, Jr. (éds.), Vol. K-3, Geological Society of America, Boulder, CO, pp. 241-260.

Benson, L. V., J. H. Robison, R. K. Blankennagel, and A. E. Ogard, 1983. Chemical Composition of Ground Water and the Locations of Permeable Zones in the Yucca Mountain Area, Nevada, USGS-OFR-83-854, Open-File Report, U.S. Geological Survey, Denver, CO.

Benson, L. V., D. R. Currey, R. I. Dorn, K. R. Lajoie, C. G. Oviatt, S. W. Robinson, G. I. Smith, and S. Stine, 1990. Chronology of Expansion and Contraction of Four Great Basin Lake Systems During the Past 35,000 Years, Palaeogeography, Palaeoclimatology, Palaeoecology, Vol. 78, pp. 241-286.

Bergquist, J. R., and E. H. McKee, 1991. Mines, Prospects, and Mineral Occurrences in Esmeralda and Nye Counties, Nevada, Near Yucca Mountain, U.S. Geological Survey Administrative Report to the U.S. Department of Energy, Yucca Mountain Project, Washington, DC.

Berry, W. E., 1983. Durability of Marker Materials for Nuclear Waste Isolation Sites, ONWI-474, Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, OH.

Bierman, P. R., and A. R. Gillespie, 1991. Accuracy of Rock-Varnish Chemical Analyses: Implications for Cation-Ratio Dating, Geology, Vol. 19, No. 3, pp. 196-199.

Bish, D. L., 1988a. Effects of Composition on the Dehydration Behavior of Clinoptilolite and Heulandite, Proceedings of the International Conference on the Occurrence, Properties, and Utilization of Natural Zeolites, April 12-15, 1985, Budapest, Hungary, pp. 565-576.

Bish, D. L., 1988b. Smectite Dehydration and Stability: Applications to Radioactive Waste Isolation at Yucca Mountain, Nevada, LA-11023-MS, Los Alamos National Laboratory, Los Alamos, NM.

Bish, D. L., 1989. Evaluation of Past and Future Alterations in Tuff at Yucca Mountain, Nevada, Based on the Clay Mineralogy of Drill Cores USW G-1, G-2, and G-3, LA-10667-MS, Los Alamos National Laboratory, Los Alamos, NM.

Bish, D. L., and S. J. Chipera, 1986. Mineralogy of Drill Holes J-13, UE-25A#1, and USW G-1 at Yucca Mountain, Nevada, LA-10764-MS, Los Alamos National Laboratory, Los Alamos, NM.

Bish, D. L., and S. J. Chipera, 1989. Revised Mineralogic Summary of Yucca Mountain, Nevada, LA-11497-MS, Los Alamos National Laboratory, Los Alamos, NM.

Bish, D. L., and D. T. Vaniman, 1985. Mineralogic Summary of Yucca Mountain, Nevada, LA-10543-MS, Los Alamos National Laboratory, Los Alamos, NM.

Bixler, N. E., 1985. NORIA--A Finite Element Computer Program for Analyzing Water, Vapor, Air, and Energy Transport in Porous Media, SAND84-2057, Sandia National Laboratories, Albuquerque, NM.

Blakely, R. J., and R. C. Jachens, 1991. Regional Study of Mineral Resources in Nevada: Insights from Three-Dimensional Analysis of Gravity and Magnetic Anomalies, Geological Society of America Bulletin, Vol. 103, No. 6, pp. 795-803.

Blejwas, T. E., 1991. Letter from T. E. Blejwas (Sandia National Laboratories) to C. P. Gertz (U.S. Department of Energy, Nevada), February 28, 1991; regarding Surface-Based Data Needed for ESF Design.

Bohannon, R. G., 1983. Mesozoic and Cenozoic Tectonic Development of the Muddy, North Muddy, and Northern Black Mountains, Clark County, Nevada, Tectonic and Stratigraphic Studies in the Eastern Great Basin, Geological Society of America Memoir 157, Boulder, CO, pp. 125-148.

Bonham, H. F., Jr., 1988. Models for Volcanic-Hosted Epithermal Precious Metal Deposits, in Bulk Mineable Precious Metal Deposits of the Western United States, The Geological Society of Nevada, Symposium Proceedings, April 6-8, 1988, R. R. Schaefer, J. J. Cooper, and P. G. Vikre (eds.), Reno, pp. 259-271.

Bonham, H. F., Jr., 1989. Bulk-Mineable Precious-Metal Deposits, The Nevada Mineral Industry 1988, Nevada Bureau of Mines & Geology Special Publication MI-1988, University of Nevada, Reno, pp. 19-26.

Bonham, H. F., Jr., and R. H. Hess, 1990. Bulk-Mineable Precious-Metal Deposits, The Nevada Mineral Industry 1989, Nevada Bureau of Mines & Geology Special Publication MI-1989, University of Nevada, Reno, pp. 19-25.

Bonilla, M. G., 1988. Minimum Earthquake Magnitude Associated with Coseismic Surface Faulting, Bulletin of the Association of Engineering Geologists, Vol. XXV, No. 1, pp. 17-29.

Bonilla, M. G., R. K. Mark, and J. J. Lienkaemper, 1984. Statistical Relations Among Earthquake Magnitude, Surface Rupture Length, and Surface Fault Displacement, Bulletin of the Seismological Society of America, Vol. 74, No. 6, pp. 2379-2411.

Bradbury, J. P., R. M. Forester, and R. S. Thompson, 1989. Late Quaternary Paleolimnology of Walker Lake, Nevada, Journal of Paleolimnology, Vol. 1, pp. 249-267.

Brady, B. T., 1989. Mineral and Energy Resources in Studies of Geology and Hydrology in the Basin and Range Province, Southwestern United States, for Isolation of High-Level Radioactive Waste-Characterization of the Death Valley Region, Nevada and California, M.S. Bedinger, K.A. Sargent, and W.H. Langer (eds.), U.S. Geological Survey Professional Paper 1370-F, U.S. Government Printing Office, Washington, DC, pp. F36-F49.

Brooks, J. W., L. D. Meinert, B. A. Kuyper, and M. L. Lane, 1991. Petrology and Geochemistry of the McCoy Gold Skarn, Lander County, Nevada, in Geology and Ore Deposits of the Great Basin, Geological Society of Nevada Symposium Proceedings, April 1-5, 1990, Reno, pp. 419-442.

Brown, S. R., 1987. Fluid Flow Through Rock Joints: The Effect of Surface Roughness, Journal of Geophysical Research, Vol. 92, No. B2, pp. 1337-1347.

Broxton, D. E., R. G. Warren, R. C. Hagan, and G. Luedemann, 1986. Chemistry of Diagenetically Altered Tuffs at a Potential Nuclear Waste Repository, Yucca Mountain, Nye County, Nevada, LA-10802-MS, Los Alamos National Laboratory, Los Alamos, NM.

Broxton, D. E., D. L. Bish, and R. G. Warren, 1987. Distribution and Chemistry of Diagenetic Minerals at Yucca Mountain, Nye County, Nevada, Clays and Clay Minerals, Vol. 35, No. 2, pp. 89-110.

Bruton, C. J., and B. E. Viani, 1990. Geochemical Modeling of Water/ Clinoptilolite Interactions, Abstract UCRL-JC-104527, presented at Geological Society of America Meeting, October 29 - November 1, 1990, Dallas, TX, (Lawrence Livermore National Laboratory, Livermore, CA.)

Brutsaert, W., 1987. Some Methods of Calculating Unsaturated Permeability, Transactions of the American Society of Agricultural Engineers, Vol. 10, No. 3, pp. 400-404.

Bull, W. B., and T.-L. Ku 1975. Age Dating of the Late Cenozoic Deposits in the Vicinity of the Vidal Nuclear Generating Station Site, Appendix 2.5G, Woodward-Clyde Consultants, Oakland, CA.

Bullard, K. L., 1986. PMF (Probable Maximum Flood) Study for Nevada Nuclear Waste Storage Investigations Project, GR-87-8, Engineering and Research Center, Bureau of Reclamation, Denver, CO.

Burchfiel, B. C., 1965. Structural Geology of the Specter Range Quadrangle, Nevada, and Its Regional Significance, Geological Society of America Bulletin, Vol. 76, pp. 175-192.

Buscheck, T. A., 1991. Hydrogeologic Uncertainties, unpublished presentation to the Nuclear Waste Technical Review Board, October 8-10, 1991, Las Vegas, Nevada, Lawrence Livermore National Laboratory, Livermore, CA.

Buscheck, T. A., and J. J. Nitao, 1991a. Nonequilibrium Fracture-Matrix Flow During Episodic Infiltration Events in Yucca Mountain, in Proceedings of the Fifth NRC Workshop on Flow and Transport through Unsaturated Fractured Rock, University of Arizona, Tuscon, Jan 7-10, 1991, draft NUREG-CP-0040, CNWRA-91007, U.S. Nuclear Regulatory Commission, Washington, DC.

Buscheck, T. A., and J. J. Nitao, 1991b. Modeling Hydrothermal Flow in Variably Saturated, Fractured, Welded Tuff During the Prototype Engineered Barrier System Field Test of the Yucca Mountain Project, UCRL-JC-106521, preprint, Lawrence Livermore National Laboratory, Livermore, CA.

Buscheck, T. A., J. J. Nitao, and D. A. Chesnut, 1991a. Hydrothermal Modeling: Nearfield Environment Report, draft, Lawrence Livermore National Laboratories, Livermore, CA.

Buscheck, T., R. Carlson, W. Daily, K. Lee, W. Lin, N. H. Mao, A. Ramirez, T. S. Ueng, H. Wang, and D. Watwood, 1991b. Prototype Engineered Barrier System Field Test (PEBSFT) Final Report, UCRL-ID-106159, Lawrence Livermore National Laboratory, Livermore, CA.

Buscheck, T. A., J. J. Nitao, and D. A. Chesnut, 1991c. The Impact of Hydrology on the Engineered Barrier System of the Potential Yucca Mountain Repository Site, draft, Lawrence Livermore National Laboratories, Livermore, CA.

Byers, F. M., Jr., and L. M. Moore, 1987. Petrographic Variation of the Topopah Spring Tuff Matrix Within and Between Cored Drill Holes, Yucca Mountain, Nevada, LA-10901-MS, Los Alamos National Laboratory, Los Alamos, NM.

Byers, F. M., Jr., W. J. Carr, and P. Orkild, 1989. Stop 1: Timber Mountain Caldera, Geological Society of America 1989 Field Trip Guidebook, Special Publication Number 5, Missouri Department of Natural Resources, Rolla, MO, p. 12.

CAA (Clean Air Act), 1990. Clean Air Act as amended, Public Law 88-206, 42 U.S.C. 7401 et seq., amended by Public Laws 89-272, 89-675, 90-148, Clean Air Amendments of 1970, 91-604, 92-157, 93-15, 93-319, Clean Air Act Amendments of 1977, 95-95, 95-190, 95-623, 96-209, 96-300, 97-23, 97-375, 98-45, 98-231, 100-202, and 101-549.

COHMAP (Cooperative Holocene Mapping Project) Members, 1988. Climatic Changes of the Last 18,000 Years: Observations and Model Simulations, Science, Vol. 241, pp. 1043-1052.

Campbell, K., 1987. Lateral Continuity of Sorptive Mineral Zones Underlying Yucca Mountain, Nevada, LA-11070-MS, Los Alamos National Laboratory, Los Alamos, NM.

Campbell, K. W., 1982. A Preliminary Methodology for the Regional Zonation of Peak Ground Acceleration, in Proceedings of the Third International Microzonation Conference Proceedings, Seattle, Washington, June 28 - July 1, 1982, Vol. 1, pp. 365-376.

Carlos, B. A., 1987. Minerals in Fractures of the Saturated Zone from Drill Core USW G-4, Yucca Mountain, Nye County, Nevada, LA-10927-MS, Los Alamos National Laboratory, Los Alamos, NM.

Carlos, B. A., D. L. Bish, and S. J. Chipera, 1991. Fracture-Lining Minerals in the Lower Topopah Spring Tuff at Yucca Mountain, LA-UR-90-4354, Los Alamos National Laboratory, Los Alamos, NM, pp. 486-493.

Carr, M. D., and S. A. Monsen, 1988. A Field Trip Guide to the Geology of Bare Mountain, This Extended Land: Geological Journeys in Southern Basin and Range, D. L. Wade and M. L. Faber (eds.), Department of Geoscience, University of Nevada, Las Vegas, pp. 50-56.

Carr, M. D., S. J. Waddell, G. S. Vick, J. M. Stock, S. A. Monsen, A. G. Harris, B. W. Cork, and F. M. Byers, Jr., 1986. Geology of Drill Hole UE25p#1: A Test Hole into Pre-Tertiary Rocks near Yucca Mountain, Southern Nevada, USGS-OFR-86-175, draft, Open-File Report, U.S. Geological Survey.

Carr, W. J., 1984. Regional Structural Setting of Yucca Mountain, Southwestern Nevada, and Late Cenozoic Rates of Tectonic Activity in Part of the Southwestern Great Basin, Nevada and California, USGS-OFR-84-854, draft, Open-File Report, U.S. Geological Survey, Denver, CO.

Carr, W. J., 1988. Styles of Extension in the Nevada Test Site Region, Southern Walker Lane Belt: An Integration of Volcano-Tectonic and Detachment Fault Models, SAND87-7081A, abstract, Presented at Annual Meeting Geological Society of America, Cordilleran Section, March 29-31, 1988, Las Vegas, Nevada, Sandia National Laboratories, Albuquerque, NM.

Carr, W. J., F. M. Byers, Jr., and P. P. Orkild, 1986. Stratigraphic and Volcano-Tectonic Relations of Crater Flat Tuff and Some Older Volcanic Units, Nye County, Nevada, U.S. Geological Survey Professional Paper 1323, U.S. Government Printing Office, Washington, DC.

Carrigan, C. R., and G. C. P. King, 1991. Models of Water Table Excursions by Seismic and Volcanic Events at Yucca Mountain, Nevada, AGU-MSA Spring Meeting 1991 Program and Abstracts, Supplement to EOS, April 23, 1991, American Geophysical Union, Vol. 72, No. 17, Washington, DC, p. 116.

Carter, R. A., 1990. A Record Year for Nevada Gold, E&MJ, Engineering and Mining Journal, June, 1990, pp. 36-39.

Case, J. B., and P. C. Kelsall, 1987. Modification of Rock Mass Permeability in the Zone Surrounding a Shaft in Fractured, Welded Tuff, SAND86-7001, Sandia National Laboratories, Albuquerque, NM.

Castor, S. B., 1989. Industrial Minerals, The Nevada Mineral Industry 1988, Nevada Bureau of Mines & Geology Special Publication MI-1988, University of Nevada, Reno, pp. 27-29.

Castor, S. B., 1990. Industrial Minerals, The Nevada Mineral Industry 1989 Nevada Bureau of Mines & Geology Special Publication MI-1989, University of Nevada, Reno, pp. 26-29.

Castor, S. B., S. C. Feldman, and J. V. Tingley, 1989. Mineral Evaluation of the Yucca Mountain Addition, Nye County, Nevada, Nevada Bureau of Mines and Geology Open-File Report 90-4, draft, Reno, NV, 80 pp.

Cerling, T. E., and J. Quade, 1991. Using Light Stable Isotopic Tracers to Distinguish between Groundwater Discharge and Vadose Zone Carbonates, AGU-MSA Spring Meeting 1991 Program and Abstracts, Supplement to EOS, April 23, 1991, American Geophysical Union, Washington, DC, p. 116.

Chamberlain, A. K., 1987. Depositional Environments and Hydrocarbon Occurrence of Mississippian Antler Basin, Nevada and Utah, AAPG Bulletin, Vol. 71, No. 8, pp. 1002-1003.

Chamberlain, A. K., 1991. Yucca Mountain, a High-Level Nuclear Waste Repository Over a Billion Barrel Oil Field? AAPG Bulletin, Vol. 75, No. 3, p. 551.

Champion, D. E., 1991. Volcanic Episodes near Yucca Mountain as Determined by Paleomagnetic Studies at Lathrop Wells, Crater Flat, and Sleeping Butte, Nevada, in High Level Radioactive Waste Management, Proceedings of the Second Annual International Conference, Las Vegas, Nevada, April 28-May 3, 1991, Vol. 1, American Nuclear Society, Inc., La Grange Park, IL, pp. 61-67.

Chipera, S. J., and D. L. Bish, 1988. Mineralogy of Drill Hole UE-25p#1 at Yucca Mountain, Nevada, LA-11292-MS, Los Alamos National Laboratory, Los Alamos, NM, 24 pp.

Christianson, M. C., and B. Brady, 1989. Analysis of Alternative Waste Isolation Concepts, NUREG/CR-5389, U.S. Nuclear Regulatory Commission, Washington, DC.

Clark, R. L., and F. L. Galpin, 1991. Status and Outlook for the USEPA'S Environmental Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes (40 CFR Part 191), for presentation at Waste Management '91, Annual Symposium, February 24-28, 1991, Tucson, Arizona, pp. 1-9.

Combes, J. M., C. J. Chisholm-Brause, G. E. Brown, Jr., G. A. Parks, S. D. Conradson, P. G. Eller, I. R. Triay, and A. Meijer, 1990. EXAFS Spectroscopic Study of Neptunium(V) Sorption at the a-FeOOH/Water Interface, Yucca Mountain Project Monthly Activity Report, JWS-EES-13-11-90-066, Los Alamos National Laboratory, Los Alamos, NM, pp. 1-13.

Coope, J. A., 1991. Carlin Trend Exploration History: Discovery of the Carlin Deposit, Nevada Bureau of Mines and Geology Special Publication 13, Mackay School of Mines, University of Nevada, Reno.

Coppersmith, K. J., 1990. Incorporating Seismotectonic Data into Seismic Hazard Analyses, in High Level Radioactive Waste Management, Proceedings of the International Topical Meeting, April 8-12, 1990, Las Vegas, Nevada, Vol. 1, American Nuclear Society, Inc., La Grange Park, IL, pp. 91-95.

Coppersmith, K. J., and R. R. Youngs, 1990. Earthquakes and Tectonics, Section 3, Demonstration of a Risk-Based Approach to High-Level Waste Repository Evaluation, EPRI NP-7057, Electric Power Research Institute, Palo Alto, CA.

Cornwall, H. R., 1972. Geology and Mineral Deposits of Southern Nye County, Nevada, Nevada Bureau of Mines & Geology Bulletin 77, Mackay School of Mines, University of Nevada, Reno.

Cornwall, H. R., and F. J. Kleinhampl, 1961. Geology of the Bare Mountain Quadrangle, Nevada, U.S. Geological Survey Quadrangle Map GQ-157, Scale 1:62,500, U.S. Geological Survey.

Cornwall, H. R., and F. J. Kleinhampl, 1964. Geology of the Bullfrog Quadrangle and Ore Deposits Related to the Bullfrog Hills Caldera, Nye County, Nevada and Inyo County, California, U.S. Geological Survey Professional Paper 454-J, U.S. Government Printing Office, Washington, DC.

Courtier, R.J., 1989. Letter from Col. Robert J. Courtier (U.S. Air Force) to B. Kaiser/C. Gertz (U.S. Department of Energy, Nevada), July 6, 1989, Langley Air Force Base, VA; regarding Site Characterization Activities - Yucca Mountain.

Craig, R. W., and J. H. Robison, 1984. Geohydrology of Rocks Penetrated by Test Well UE-25p#1, Yucca Mountain Area, Nye County, Nevada, USGS-WRI-84-4248, Water-Resources Investigations Report, U.S. Geological Survey.

Crowe, B. M., 1986. Volcanic Hazard Assessment for Disposal of High Level Radioactive Waste, Chapter 16, Active Tectonics, National Academy Press, Washington, DC, pp. 247-260.

Crowe, B. M., 1990. Basaltic Volcanic Episodes of the Yucca Mountain Region, in High Level Radioactive Waste Mangement, Proceedings of the International Topical Meeting, April 8-12, 1990, Las Vegas, Nevada, Vol. 1, American Nuclear Society, Inc., La Grange Park, IL, pp. 65-73.

Crowe, B., 1991a. Memorandum from B. Crowe (Los Alamos National Laboratory) to D. Dobson (Yucca Mountain Project Office), July 15, 1991; regarding Review of the Volcanism Geochronology Program.

Crowe, B. M., 1991b. Memorandum from B. Crowe (Los Alamos National Laboratory) to W. Dudley (U.S. Geological Survey), July 18, 1991; regarding Information for the Early Site Suitability Evaluation on Preclosure Hazards of Basaltic and Silicic Volcanism.

Crowe, B. M., and W. J. Carr, 1980. Preliminary Assessment of the Risk of Volcanism at a Proposed Nuclear Waste Repository in the Southern Great Basin, USGS-OFR-80-357, Open-File Report, U.S. Geological Survey.

Crowe, B. M., and F. V. Perry, 1989. Volcanic Probability Calculations for the Yucca Mountain Site: Estimation of Volcanic Rates, in FOCUS '89, Proceedings of the Topical Meeting on Nuclear Waste Isolation in the Unsaturated Zone, September 17-21, 1989, Las Vegas, Nevada, American Nuclear Society, Inc., La Grange Park, IL, pp. 326-334.

Crowe, B. M., M. E. Johnson, and R. J. Beckman, 1982. Calculation of the Probability of Volcanic Disruption of a High-Level Radioactive Waste Repository within Southern Nevada, USA, Radioactive Waste Management and the Nuclear Fuel Cycle, Vol. 3, No. 2, pp. 167-190.

Crowe, B. M., S. Self, D. Vaniman, R. Amos, and F. Perry, 1983a. Aspects of Potential Magmatic Disruption of a High-Level Radioactive Waste Repository in Southern Nevada, Journal of Geology, Vol. 91, pp. 259-276.

Crowe, B. M., D. T. Vaniman, and W. J. Carr, 1983b. Status of Volcanic Hazard Studies for the Nevada Nuclear Waste Storage Investigations, LA-9325-MS, Los Alamos National Laboratory, Los Alamos, NM.

Crowe, B. M., K. H. Wohletz, D. T. Vaniman, E. Gladney, and N. Bower, 1986. Status of Volcanic Hazard Studies for the Nevada Nuclear Waste Storage Investigations, LA-9325-MS, Vol. II, Los Alamos National Laboratory, Los Alamos, NM.

Crowe, B., C. Harrington, L. McFadden, F. Perry, S. Wells, B. Turrin, and D. Champion, 1988a. Preliminary Geologic Map of the Lathrop Wells Volcanic Center, LA-UR-88-4155, Los Alamos National Laboratory, Los Alamos, NM.

Crowe, B. M., F. V. Perry, B. D. Turrin, S. G. Wells, and L. D. MacFadden, 1988b. Volcanic Hazard Assessment for Storage of High-Level Radioactive Waste at Yucca Mountain, Nevada, Annual Meeting Geological Society of America, Cordilleran Section, March 29-31, 1988, Las Vegas, Nevada, Abstracts with Programs, Vol. 20, No. 3, p. 153.

Crowe, B. M., C. Harrington, B. Turrin, D. Champion, S. Wells, F. Perry, L. McFadden, and C. Renault, 1989. Volcanic Hazard Studies for the Yucca Mountain Project, in Waste Management 89, Proceedings of the Symposium, February 26 - March 2, 1989, Tucson, Arizona, Vol. 1, pp. 485-491.

Czarnecki, J. B., 1985. Simulated Effects of Increased Recharge on the Ground-Water Flow System of Yucca Mountain and Vicinity, Nevada-California, USGS-WRI-84-4344, Water-Resources Investigations Report, U.S. Geological Survey.

Czarnecki, J. B., 1989a. Characterization of the Subregional Ground-Water Flow System at Yucca Mountain and Vicinity, Nevada-California, Radioactive Waste Management and the Nuclear Fuel Cycle, Vol. 13, pp. 51-61.

Czarnecki, J. B., 1989b. Preliminary Simulations Related to a Large Horizontal Hydraulic Gradient at the North End of Yucca Mountain, Nevada, EOS, Transactions, American Geophysical Union, Vol. 70, No. 15, p. 321.

Czarnecki, J. B., 1990a. Geohydrology and Evapotranspiration at Franklin Lake Playa, Inyo County, California, USGS-OFR-90-356, Open-File Report, U.S. Geological Survey.

Czarnecki, J. B., 1990b. Should the Furnace Creek Ranch-Franklin Lake Playa Ground-water Subbasin Simply be the Franklin Lake Playa Ground-water Subbasin? Field Trip to Yucca Mountain and Surrounding Region for the National Academy of Sciences Panel on Coupled Processes, October 18-20, 1990, Yucca Mountain Project, Las Vegas, NV, p. 70.

Czarnecki, J. B., 1991a. Internal memorandum from J. B. Czarnecki (USGS) to L. Hayes, April 25, 1991, U.S. Geological Society; regarding Conversion of Planned Oil Wells in the Amargosa Desert.

Czarnecki, J. B., 1991b. Preliminary Simulations Showing Potential Effects of a Wetter Future Climate Coupled with a Localized Increase in Hydraulic Conductivity on the Ground-Water Flow System of Yucca Mountain and Vicinity, Nevada-California, AGU-MSA Spring Meeting 1991 Program and Abstracts, Supplement to EOS, April 23, 1991, American Geophysical Union, Washington, DC, p. 121.

Czarnecki, J. B., and R. R. Luckey, 1989. Regional and Local Flow Systems near Yucca Mountain, Nevada, Geological Society of America 1989 Field Trip Guidebook, J. D. Vineyard and W. K. Wedge (comps.), Special Publication No. 5, Missouri Department of Natural Resources, Rolla, pp. 32-33.

DOE (U.S. Department of Energy), 1986. Final Environmental Assessment: Yucca Mountain Site, Nevada Research and Development Area, Nevada, 3 volumes, DOE/RW-0073, Office of Civilian Radioactive Waste Management, Washington, DC.

DOE (U.S. Department of Energy), 1987a. Real Property and Site Development Planning, DOE Order 4300.1B, Washington, DC.

DOE (U.S. Department of Energy), 1987b. The Nevada Nuclear Waste Storage Investigations Project Reference Information Base, Version 03.001, NNWSI/88-5, Nevada Operations Office, Las Vegas, NV.

DOE (U.S. Department of Energy), 1988a. Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada DOE/RW-0199, 9 volumes, Office of Civilian Radioactive Waste Management, Washington, DC.

DOE (U.S. Department of Energy), 1988b. Section 175 Report: Secretary of Energy's Report to the Congress Pursuant to Section 175 of the Nuclear Waste Policy Act, As Amended, DOE/RW-0205, Office of Civilian Radioactive Waste Managment, Washington, DC.

DOE (U.S. Department of Energy), 1988c. Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada, 7 volumes, DOE/RW-0160, Office of Civilian Radioactive Waste Management, Washington, DC.

DOE (U.S. Department of Energy), 1988d. Programmatic Agreement Between the United States Department of Energy and the Advisory Council on Historic Preservation, Washington, DC.

DOE (U.S. Department of Energy), 1989a. Exploratory Shaft Facility (ESF) Title I Design Acceptability Analysis and Comparative Evaluation of Alternative ESF Locations, YMP/89-3, Nevada Operations Office/Yucca Mountain Project Office, Las Vegas, NV.

DOE (U.S. Department of Energy), 1989b. Nevada Highway Routing Study, DOE/NV-10576-7, Nevada Operations Office, Las Vegas, NV.

DOE (U.S. Department of Energy), 1990a. Characterization of Flood Potential and Debris Hazards of the Yucca Mountain Site, YMP-USGS-SP 8.3.1.16.1.1, Rev. 0, Office of Civilian Radioactive Waste Management, Washington, DC.

DOE (U.S. Department of Energy), 1990b. Exploratory Shaft Facility (ESF) Subsystem Design Requirements Document (SDRD) for Title II, YMP/CM-0006, 2 volumes, Yucca Mountain Project Office, Las Vegas, NV.

DOE (U.S. Department of Energy), 1990c. Management Agreement Between Nevada Operations Office and the Yucca Mountain Site Characterization Project Office, unpublished draft, December, 1990, Las Vegas, NV.

DOE (U.S. Department of Energy), 1990d. Performance Assessment Implementation Plan for the Geologic Repository Program, DOE/RW-0267P, Office of Civilian Radioactive Waste Management, Washington, DC.

DOE (U.S. Department of Energy), 1990e. Preliminary Nevada Transportation Accident Characterization Study, YMP-90-42, Yucca Mountain Project Office, Las Vegas, NV.

DOE (U.S. Department of Energy), 1990f. Preliminary Rail Access Study, DOE/YMP-89-16, Nevada Operations Office, Yucca Mountain Project Office, Las Vegas, NV.

DOE (U.S. Department of Energy), 1990g. Research Design and Data Recovery Plan for Yucca Mountain Project, Yucca Mountain Project Office, Las Vegas, NV.

DOE (U.S. Department of Energy), 1990h. Site Specific Plan for Environmental Restoration and Waste Management (five year plan), DOE/NV-336, Nevada Operations Office, Las Vegas, NV.

DOE (U.S. Department of Energy), 1990i. Yucca Mountain Project Bibliography 1988-1989, DOE/OSTI-3406, Suppl. 2, Office of Scientific and Technical Information, Oak Ridge, TN.

DOE (U.S. Department of Energy), 1990j. Test and Evaluation Plan, YMP/90-22, Yucca Mountain Project Office, Las Vegas, NV

DOE (U.S. Department of Energy), 1991a. Characterization of the Meteorology for Regional Hydrology, YMP-USGS-SP 8.3.1.2.1.1, Rev. 0, Office of Civilian Radioactive Waste Management, Washington, DC.

DOE (U.S. Department of Energy), 1991b. Draft Mission Plan Amendment, DOE/RW-0316P, Office of Civilian Radioactive Waste Management, Washington, DC.

DOE (U.S. Department of Energy), 1991c. Monitoring Program for Ground-Water Levels and Springflows in the Yucca Mountain Region of Southern Nevada and California, Yucca Mountain Project Office, Las Vegas, NV.

DOE (U.S. Department of Energy), 1991d. Risk/Benefit Analysis of Alternative Strategies for Characterizing the Calico Hills Unit at Yucca Mountain, Record Memorandum YMP/90-3, 2 volumes, Yucca Mountain Project Office, Las Vegas, NV.

DOE (U.S. Department of Energy), 1991e. Socioeconomic Plan, Rev. 0, YMP/91-21, Yucca Mountain Site Characterization Project Office, Las Vegas, NV.

DOE (U.S. Department of Energy), 1991f. The Yucca Mountain Site Characterization Project Reference Information Base, Version 4, Rev. 4, YMP/CC-0002, Yucca Mountain Site Characterization Project Office, Las Vegas, NV.

DOE (U.S. Department of Energy), 1991g. Unsaturated Zone Hydrology Peer Review Record Memorandum, Yucca Mountain Site Characterization Project Office, Las Vegas, NV.

DOE (U.S. Department of Energy), 1991h. Planning and Preparedness for Operational Emergencies, DOE Order 5500.3A, Washington, DC.

Dagan, G., 1987. Review of Stochastic Theory of Transport in Groundwater Flow, Groundwater Flow and Quality Modeling, E. Custodio, A. Gurgui, and J. P. Lobo Ferreira, (eds.), Reidel Publishers, Dordrecht, The Netherlands, pp. 1-32.

De Leuw, Cather & Company, 1991. Yucca Mountain Rail Access Study: Caliente Route, Conceptual Design Report, Executive Summary Draft, De Leuw, Cather & Company, San Fransicso, CA.

Dennis, A. W., (ed.), 1991. Exploratory Studies Facility Alternatives Study: Final Report, SAND91-0025, 2 volumes, Sandia National Laboratories, Albuquerque, NM.

dePolo, C. M., J. W. Bell, and A. R. Ramelli, 1990. Estimating Earthquake Sizes in the Basin and Range Province, Western North America: Perspectives Gained from Historical Earthquakes, in High Level Radioactive Waste Management, Proceedings of the International Topical Meeting, April 8-12, 1990, Las Vegas, Nevada, Vol. 1, American Nuclear Society, Inc., La Grange Park, IL, pp. 117-123.

Dickinson, R. E., R. M. Errico, F. Giorgi, and G. T. Bates, 1989. A Regional Climate Model for the Western United States, Climate Change, Vol. 15, pp. 383-422.

Dorn, R. I., A. J. T. Jull, D. J. Donahue, T. W. Linick, and L. J. Toolin, 1990. Latest Pleistocene Lake Shorelines and Glacial Chronology in the Western Basin and Range Province, U.S.A.: Insights from AMS Radiocarbon Dating of Rock Varnish and Paleoclimatic Implications, Palaeogeography, Palaeoclimatology, Palaeoecology, Vol. 78, pp. 315-331.

Doser, D. I., 1989. Source Parameters of Montana Earthquakes (1925-1964) and Tectonic Deformation in the Northern Intermountain Seismic Belt, Bulletin of the Seismological Society of America, Vol. 79, No. 1, pp. 31-50.

Dreier, J., 1984. Regional Tectonic Control of Epithermal Veins in the Western United States and Mexico, Arizona Geological Society Digest, Vol. 15., pp. 28-50.

Dudley, A. L., R. R. Peters, J. H. Gauthier, M. L. Wilson, M. S. Tierney, and E. A. Klavetter, 1988. Total System Performance Assessment Code (TOSPAC) Volume 1: Physical and Mathematical Bases, SAND85-0002, Sandia National Laboratories, Albuquerque, NM.

Dudley, W. W., Jr., 1990a. Multidisciplinary Hydrologic Investigations at Yucca Mountain, Nevada, in High Level Radioactive Waste Management, Proceedings of the International Topical Meeting, April 8-12, 1990, Las Vegas, Nevada, Vol. 1, American Nuclear Society, Inc., La Grange Park, IL, pp. 1-9.

Dudley, W., 1990b. Stop 16, Bailey Hot Spring, Field Trip to Yucca Mountain and Surrounding Region for the National Academy of Sciences Panel on Coupled Processes, October 18-20, 1990, Yucca Mountain Project, Las Vegas, NV, pp. 58-62.

Dudley, W., 1990c. Stop 18, Overview of Greenwater/Black Mountain Area and Franklin Well, Field Trip to Yucca Mountain and Surrounding Region for the National Academy of Sciences Panel on Coupled Processes, October 18-20, 1990, Yucca Mountain Project, Las Vegas, NV, pp. 66-69.

Dudley, W. W., Jr., and J. D. Larson, 1976. Effect of Irrigation Pumping on Desert Pupfish Habitats in Ash Meadows, Nye County, Nevada, U.S. Geological Survey Professional Paper 927, U.S. Government Printing Office, Washington, DC.

Dudley, W. W., Jr., G. E. Barr, D. A. Chesnut, and C. J. Fridrich (eds.), 1989. Review of a Conceptual Model and Evidence for Tectonic Control of the Ground-Water System in the Vicinity of Yucca Mountain, Nevada, unnumbered report, U.S. Department of Energy, Yucca Mountain Project Office, Las Vegas, NV.

Durham, W. B., J. M. Beiriger, M. Axelrod, and S. Trettenero, 1986. The Effect of Gamma Irradiation on the Strength and Elasticity of Climax Stock and Westerly Granites, Nuclear and Chemical Waste Management, Vol. 6, pp. 159-168.

Dykhuizen, R. C., 1991. Dual Porosity Models for Solute Transport at Yucca Mountain, SAND90-2619, Sandia National Laboratories, Albuquerque, NM.

Dykhuizen, R. C., and R. R. Eaton, 1990. Internal memorandum from R. C. Dykhuizen and R. R. Eaton to P. Kaplan, Sept. 27, 1990, Sandia National Laboratories, Albuquerque, NM; regarding apparent conductivity across a fracture: The non-linear case.

Dykhuizen, R. C., and R. R. Eaton, 1991. Effect of Material Heterogeneities on Flow Through Porous Media, in High Level Radioactive Waste Management, Proceedings of the Second Annual International Conference, Las Vegas, Nevada, April 28-May 3, 1991, Vol. 1, American Nuclear Society, Inc., La Grange Park, IL, pp. 529-534.

Dykhuizen, R. C., and M. J. Martinez, 1991. Internal memorandum from R. C. Dykhuizen and M. J. Martinez to P. Kaplan, Sandia National Laboratories, Albuquerque, NM; regarding effect of point source boundary conditions.

Dykhuizen, R. C., R. R. Eaton, P. L. Hopkins, and M. J. Martinez, 1991, PACE-90 Water and Solute Transport Calculations for 0.01, 0.1, and 0.5 mm/yr Infiltration into Yucca Mountain, SAND90-3165, Sandia National Laboratories, Albuquerque, NM.

E&MJ (Engineering and Mining Journal), 1991. Report on Mineral Availability in Nevada Released, May, 1991, p. 16M.

EG&G, Energy Measurements, 1991. Yucca Mountain Biological Resources Monitoring Program, Annual Report FY89 & FY90, EGG 10617-2084, Santa Barbara Operations, CA.

EPA (U.S. Environmental Protection Agency), 1990. Offsite Environmental Monitoring Report; Radiation Monitoring Around United States Nuclear Test Areas, Calendar Year 1989, EPA/600/4-90/016, Environmental Monitoring Systems Laboratory, Las Vegas, NV.

Ehgartner, B. L., and R. C. Kalinski, 1988. A Synopsis of Analyses (1981-87) Performed to Assess the Stability of Underground Excavations at Yucca Mountain, SAND88-2294, Sandia National Laboratories, Albuquerque, NM.

Ehni, W. J., 1987. Structure of Railroad Valley, Nye County, Nevada, AAPG Bulletin, Vol. 71, No. 8, p. 1005.

Ehni, W. J., and D. M. Evans, 1989. Oil Fields, Production Facilities and Reservoir Rocks of Northern Nye County, Nevada, First Annual Field Trip Guidebook, June 3-4, 1989, Nevada Petroleum Society, Reno.

Ellis, M. A., and J. H. Trexler, Jr., 1991. Basin-Margin Development in Pull-Apart Settings: An Example from Death Valley, California, Annual Meeting Geological Society of America, October 21-24, 1991, San Diego, California, Abstracts with Programs, Vol. 23, No. 5, p. A82.

Eslinger, P. W., T. B. Miley, and D. W. Engel, 1991. SUMO--System Performance Assessment for a High-Level Nuclear Waste Repository: Mathematical Models, draft, Pacific Northwest Laboratory, Richland, WA.

Evans, D. D., and T. C. Rasmussen, 1991. Unsaturated Flow and Transport through Fractured Rock Related to High-Level Waste Repositories, Final Report, Phase III, NUREG/CR-5581, U.S. Nuclear Regulatory Commission, Washington, DC.

Eyde, T. H., and V. Shelton, 1991. Zeolites in Industrial Minerals 1990, Mining Engineering, Vol. 43, No. 6, pp. 618-619.

Farmer, G. L., F. V. Perry, S. Semken, B. Crowe, D. Curtis, and D. J. DePaolo, 1989. Isotopic Evidence on the Structure and Origin of Subcontinental Lithospheric Mantle in Southern Nevada, Journal of Geophysical Research, Vol. 94, No B6, pp. 7885-7898.

Farmer, J. C., and R. D. McCright, 1989. Review of Models Relevant to the Prediction of Performance of High-Level Radioactive-Waste Disposal Containers, UCRL-100172, preprint, Lawrence Livermore National Laboratory, Livermore, CA.

Fernandez, J. A, P. C. Kelsall, J. B. Case, and D. Meyer, 1987. Technical Basis for Performance Goals, Design Requirements, and Material Recommendations for the NNWSI Repository Sealing Program, SAND84-1895, Sandia National Laboratories, Albuquerque, NM.

Fernandez, J. A., T. E. Hinkebein, and J. B. Case, 1988. Analyses to Evaluate the Effect of the Exploratory Shafts on Repository Performance at Yucca Mountain, SAND85-0598, Sandia National Laboratories, Albuquerque, NM.

Flanigan, D. H., 1986. The Great Basin, Oil & Gas Journal, November 10, 1986, pp. 14-16.

Fleck, R. J., 1970. Age and Possible Origin of the Las Vegas Valley Shear Zone, Clark and Nye Counties, Nevada, Annual Meeting Geological Society of America, Rocky Mountain Section, May 6-9, 1970, Rapid City, South Dakota, Abstracts with Programs, Vol. 2, No. 5, p. 333.

Fleming, K., 1990. Active Mines in Nevada, NBMG, Nevada Geology, No. 7, Summer, 1990, Nevada Bureau of Mines and Geology, Reno.

Flint, A., 1989. Characterization of Infiltration, Nuclear Waste Technical Review Board Presentation, December 11-12, 1989, Denver, CO, U.S. Geological Survey.

Flint, A. L., 1991. Characterization of Meteorology, Nuclear Waste Technical Review Board Presentation, June 25-27, 1991, Denver, CO, U.S. Geological Survey.

Foster, N. H., H. K. Veal, and C. Bortz, 1987. Fault Seals in Oil Fields in Nevada, AAPG Bulletin, Abstracts with Programs, Vol. 71, No. 8, p. 1006.

Foster, N., L. Bortz, H. Duey, A. Chamberlain, and S. Veal, 1989. Petroleum Potential of the Basin and Range Province: Central Nevada, American Geophysical Union, Field Trip Guidebook T113, Washington, DC.

Fox, K. F., Jr., and M. D. Carr, 1989. Neotectonics and Volcanism at Yucca Mountain and Vicinity, Nevada, Radioactive Waste Management and the Nuclear Fuel Cycle, Vol. 13 (1-4), Harwood Academic Publishers, pp. 37-50.

Freeze, R. A., J. Bear, M. E. Harr, R. W. Nelson, and B. Ross, 1987. Report of the Technical Advisory Committe on Uncertainties in Groundwater Travel Time Calculations at Yucca Mountain, Nevada, Revised July 27, 1987, unpublished report available from Geoscience Analysis Division of Sandia National Laboratories, Albuquerque, NM.

Freeze, R. A., L. G. Everett, G. E. Grisak, J. W. Mercer, R. W. Nelson, S. S. Papadopulos, and M. T. van Genuchten, 1991. Unsaturated Zone Hydrology Peer Review Record Memorandum, Yucca Mountain Site Characterization Project, Las Vegas, NV.

Fridrich, C. J., D. C. Dobson, and W. W. Dudley, Jr., 1991. A Geologic Hypothesis for the Large Hydraulic Gradient Under Yucca Mountain, Nevada, AGU-MSA Spring Meeting 1991 Program and Abstracts, Supplement to EOS, April 23, 1991, American Geophysical Union, Washington, DC, p. 121.

Fritz, M., 1987. Good Fortune Found in Nevada, AAPG Explorer, January, American Association of Petroleum Geologists, Tulsa, OK, pp. 14-15.

Fritz, M., 1988. Nevada Hunt Gaining Momentum, AAPG Explorer, July, American Association of Petroleum Geologists, Tulsa, OK, pp. 14-15.

Fritz, M., 1989. Nevada's Potential Endures, AAPG Explorer, August, American Association of Petroleum Geologists, Tulsa, OK, pp. 10-11.

Frizzell, V. A., Jr., and J. Shulters, 1990. Geologic Map of the Nevada Test Site, Southern Nevada, Miscellaneous Investigations Series Map I-2046, Scale 1:100,000, U.S. Geological Survey.

Gallegos, D. P., P. I. Pohl, and C. D. Updegraff, 1991. An Investigation of the Impact of Conceptual Model Uncertainty on Performance of a Hypothetical HLW Repository Site in Unsaturated, Fractured Tuff, SAND90-2882, draft, Sandia National Laboratories, Albuquerque, NM.

Galloway, D., and S. Rojstaczer, 1988. Analysis of the Frequency Response of Water Levels in Wells to Earth Tides and Atmospheric Loading, in Proceedings of the Fourth Canadian/American Conference on Hydrogeology, Banff, Alberta, Canada, June 21-24, 1988, B. Hitchon and S. Bachu (eds.) National Water Well Association, Dublin, Ohio, pp. 100-113.

Garside, L. J., 1983. Nevada Oil Shale, draft, Nevada Bureau of Mines & Geology Open-File Report 83-5, University of Nevada, Reno.

Garside, L. J., 1984. Geothermal Energy, The Nevada Mineral Industry - 1983, Nevada Bureau of Mines & Geology Special Publication MI-1983, University of Nevada, Reno, pp. 23-25.

Garside, L. J., and J. H. Schilling, 1979. Thermal Waters of Nevada, Nevada Bureau of Mines & Geology Bulletin 91, University of Nevada, Reno.

Garside, L. J., R. H. Hess, K. L. Fleming, and B. S. Weimer, 1988. Oil and Gas Developments in Nevada, Bulletin 104, Nevada Bureau of Mines and Geology Buletin 104, University of Nevada, Reno.

Gauthier, J. H., M. L. Wilson, and F. C. Lauffer, 1991. Internal memorandum from J. H. Gauthier, M. L. Wilson, and F. C. Lauffer to R. W. Barnard, April 9, 1991, Sandia National Laboratories, Albuquerque, NM; regarding site suitability, the consequences of fracture flow at Yucca Mountain.

Gelhar, L. W., 1986. Stochastic Subsurface Hydrology from Theory to Applications, Water Resources Research, Vol. 22, No. 9, pp. 135S-145S.

Gemmell, J. M., 1990. Water Levels in Periodically Measured Wells in the Yucca Mountain Area, Nevada, 1988, USGS-OFR-90-113, Open-File Report, U.S. Geological Survey.

Gertz, C. P., 1991. Letter from C. P. Gertz (U.S. Department of Energy, Nevada) to F. G. Peters (Office of Civilian Radioactive Waste Management), May 3, 1991; regarding Operations Management Tracking System RW91000243 - Analysis of Permits, Enclosure 4 identifies the water use for the Surface Based Testing activities.

Gibson, J. D., L. E. Shepard, F. H. Swan, J. R. Wesling, and F. A. Kerl, 1990. Synthesis of Studies for the Potential of Fault Rupture at the Proposed Surface Facilities, Yucca Mountain, Nevada, in High Level Radioactive Waste Management, Proceedings of the International Topical Meeting, April 8-12, 1990, Las Vegas, Nevada, Vol. 1, American Nuclear Society, Inc., La Grange Park, IL, pp. 109-116.

Glass, R. J., 1990. Laboratory Research Program to Aid in Developing and Testing the Validity of Conceptual Models for Flow and Transport Through Unsaturated Porous Media, SAND89-2359C, Sandia National Laboratories, Albuquerque, NM.

Glass, R. J., and V. C. Tidwell, 1991. Research Program to Develop and Validate Conceptual Models for Flow and Transport Through Unsaturated, Fractured Rock, in High Level Radioactive Waste Management, Proceedings of the Second Annual International Conference, April 28-May 3, 1991, Las Vegas, Nevada, Vol. 2, American Nuclear Society, Inc., La Grange Park, IL, pp. 977-987.

Golder Associates, Inc., 1990. Methodology for Evaluating Alternative Licensing Strategies Task 1: Development and Demonstration of Methodology, Preliminary Draft/ALSS 893-1197, Redmond, WA.

Greensfelder, R. W., F. C. Kintzer, and M. R. Somerville, 1980. Probable Earthquake Ground Motion as Related to Structural Response in Las Vegas, Nevada, JAB-00099-120, URS/John A. Blume & Associates, Engineers, San Francisco, CA.

Greybeck, J. D., and A. B. Wallace, 1991. Gold Mineralization at Fluorspar Canyon Near Beatty, Nye County, Nevada, in Geology and Ore Deposits of the Great Basin Symposium Proceedings, Vol. 2, Geological Society of Nevada, Reno, pp. 935-946.

Hall, S. A., 1985. Quaternary Pollen Analysis and Vegetational History of the Southwest, Pollen Records of Late-Quaternary North American Sediments, V. M. Bryant, Jr. and R. G. Holloway (eds.), American Association of Stratigraphic Palynologists Foundation, Dallas, TX, pp. 95-123.

Hamilton, W. B., 1988. Detachment Faulting in the Death Valley Region, California and Nevada, Geologic and Hydrologic Investigations of a Potential Nuclear Waste Disposal Site at Yucca Mountain, Southern Nevada, M. D. Carr, and J. C. Yount (eds.), U.S. Geological Survey Bulletin 1790, U.S. Government Printing Office, Washington, DC, pp. 51-85.

Hardyman, R. F., 1978. Volcanic Stratigraphy and Structural Geology of the Gillis Canyon Quadrangle, Northern Gillis Range, Mineral County, Nevada, unpublished Ph.D. dissertation, Mackay School of Mines, University of Nevada, Reno. pp. 203-216.

Hardyman, R. F., 1984. Strike-Slip, Normal, and Detachment Faults in Northern Gillis Range, Walker Lane of West-Central Nevada, Western Geological Excursions, J. Lintz, Jr. (ed.), Vol. 4, Annual Meetings of the Geological Society of America and affiliated societies, Reno, NV, pp. 184-231.

Hardyman, R. F., E. B. Ekren, and F. M. Byers, Jr., 1975. Cenozoic Strike-Slip, Normal, and Detachment Faults in Northern Part of the Walker Lane, West-Central Nevada, Annual Meeting Geological Society of America and associated societies, October 20-22, 1975, Salt Lake City, Utah, Abstracts with Programs, Vol. 7, No. 7, p. 1100.

Harrar, J. E., J. F. Carley, W. F. Isherwood, and E. Raber, 1990. Report of the Committee to Review the Use of J-13 Well Water in Nevada Nuclear Waste Storage Investigations, UCID-21867, Lawrence Livermore National Laboratory, Livermore, CA.

Harrington, C. D., and J. W. Whitney, 1991. Quaternary Erosion Rates on Hillslopes in the Yucca Mountain Region, Nevada, Geological Society of America Abstracts with Programs, 1991 Annual Meeting, San Diego, California, October 21-24, 1991, Vol. 23, No. 5, p. A118.

Harrington, C. D., D. J. Krier, R. Raymond, Jr., and S. L. Reneau, 1991. Barium Concentration in Rock Varnish: Implications for Calibrated Rock Varnish Dating Curves, Scanning Microscopy, Vol. 5, No. 1, pp. 55-62.

Harris, A. G., B. R. Warlow, C. C. Rust and G. K. Merrill, 1980. Maps for Assessing Thermal Maturity (Conodont Color Alteration Index Maps) in Ordovician Through Triassic Rocks in Nevada and Utah and Adjacent Parts of Idaho and California, Miscellaneous Investigations Series Map I-1249, U.S. Geological Survey.

Hartman, D. J., and D. D. Miller, 1991. Identification of Structures, Systems, and Components Important to Safety at the Potential Repository at Yucca Mountain, SAND89-7024, Sandia National Laboratories, Albuquerque, NM.

Hay, R. L., R. E. Pexton, T. T. Teague, and T. K. Kyser, 1986. Spring-Related Carbonate Rocks, Mg Clays, and Associated Minerals in Pliocene Deposits of the Amargosa Desert, Nevada and California, Geological Society of America Bulletin, Vol. 97, pp. 1488-1503.

Henton, G. H. and L. C. Pippin, 1988. Prehistoric and Historic Archaeology of Fortymile Canyon, Yucca Wash, and Midway Valley Near Yucca Mountain, Nye County, Southern Nevada, Technical Report Number 60, Desert Research Institute, University of Nevada System, Reno.

Hersman, L. E., 1986. Biodegradation of Drilling Fluids: Effects on Actinide Sorption, Milestone Report M312, Draft, Los Alamos National Laboratory, Los Alamos, NM.

Hersman, L. E., 1988. Transport by Microorganisms: Colloids, unpublished draft, Los Alamos National Laboratories, Albuquerque, NM.

Hess, R. H., and L. J. Garside, 1989. Geothermal Energy, The Nevada Mineral Industry 1988, Nevada Bureau of Mines & Geology Special Publication MI-1988, University of Nevada, Reno, pp. 53-58.

Hess, R. H., and L. J. Garside, 1990. Geothermal Energy, The Nevada Mineral Industry 1989, Nevada Bureau of Mines & Geology Special Publication MI-1989, University of Nevada, Reno, pp. 51-55.

Hildenbrand, T. G., A. M. Rogers, H. W. Oliver, S. C. Harmsen, J. K. Nakata, D. S. Aitken, R. N. Harris, and M. D. Carr, 1988. Regional Geologic and Geophysical Maps of the Southern Great Basin, Geologic and Hydrologic Investigations of a Potential Nuclear Waste Disposal Site at Yucca Mountain, Southern Nevada, M. D. Carr and J. C. Yount (eds.), U.S. Geological Survey Bulletin 1790, U.S. Geological Survey, pp. 3-21.

Ho, D. M., R. L. Sayre and C. L. Wu, 1986. Suitability of Natural Soils for Foundations for Surface Facilities at the Prospective Yucca Mountain Nuclear Waste Repository, SAND85-7107, Sandia National Laboratories, Albuquerque, NM.

Hoover, D. L., 1989. Preliminary Description of Quaternary and Late Pliocene Surficial Deposits at Yucca Mountain and Vicinity, Nye County, Nevada, USGS-OFR-89-359, Open-File Report, U.S. Geological Survey, 45 pp.

Hoover, D. L., and J. N. Morrison, 1980. Geology of the Syncline Ridge Area Related to Nuclear Waste Disposal, Nevada Test Site, Nye County, Nevada, USGS-OFR-80-942, Open-File Report, U.S. Geological Survey, 70 pp.

Hoover, D. L., W C Swadley, and A. J. Gordon, 1981. Correlation Characteristics of Surficial Deposits with a Description of Surficial Stratigraphy in the Nevada Test Site Region, USGS-OFR-81-512, Open-File Report, U.S. Geological Survey, 27 pp.

Hopkins, P. L., and R. R. Eaton, 1990. LLUVIA: A Program for One-Dimensional, Steady-State Flow Through Partially Saturated Porous Media, SAND88-0558, Sandia National Laboratories, Albuquerque, NM.

Hoxie, D. T., 1989. A Conceptual Model for the Unsaturated-Zone Hydrogeologic System, Yucca Mountain, Nevada, Radioactive Waste Management and the Nuclear Fuel Cycle, Vol. 13 (1-4), pp. 63-75.

Huber, N. K., 1988. Late Cenozoic Evolution of the Upper Amargosa River Drainage System, Southwestern Great Basin, Nevada and California, USGS-OFR-87-617, Open-File Report, U.S. Geological Survey, 26 pp.

Hulen, J. B., S. R. Bereskin, and L. C. Bortz, 1990. High-Temperature Hydrothermal Origin for Fractured Carbonate Reservoirs in the Blackburn Oil Field, Nevada, The American Association of Petroleum Geologists Bulletin, Vol. 74, No. 8, pp. 1262-1272.

Human Interference Task Force, 1984. Reducing the Likelihood of Future Human Activities That Could Affect Geologic High-Level Waste Repositories, BMI/ONWI-537, Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, OH.

Hunter, T. O., 1989. Letter from T. O. Hunter (Sandia National Laboratories) to C. P. Gertz (U.S. Department of Energy, Nevada), May 30, 1989; regarding Location of the Interface Between the TSw1 and TSw2 Formations and Its Potential Impact on the Design of the Exploratory Shaft Facility (ESF) and the Repository.

Huyakorn, P. S., B. H. Lester, and C. R. Faust, 1983. Finite Element Techniques for Modeling Groundwater Flow in Fractured Aquifers, Water Resources Research, Vol. 19, No. 4, pp. 1019-1035.

IPCC (Intergovernmental Panel on Climate Change), 1990. Scientific Assessment of Climate Change, World Meteorological Organization/United Nations Environment Programme, Geneva.

Jack R. Benjamin and Associates, Inc., Risk Engineering, Inc., and Woodward-Clyde Consultants, 1988a. Seismic Hazard Methodology for the Central and Eastern United States, Volume 1, Part 1: Theory, EPRI-NP-4726-A, Electric Power Research Institute, Palo Alto, CA.

Jack R. Benjamin and Associates, Inc., Risk Engineering, Inc., and Woodward-Clyde Consultants, 1988b. Seismic Hazard Methodology for the Central and Eastern United States, Volume 1, Part 2: Methodology (Revision 1), EPRI NP-4726-A, Electric Power Research Institute, Palo Alto, CA.

Jackson, J. L., H. F. Gram, K. J. Hong, H. S. Ng, and A. M. Pendergrass, 1984. Preliminary Safety Assessment Study for the Conceptual Design of a Repository in Tuff at Yucca Mountain, SAND83-1504, Sandia National Laboratories, Albuquerque, NM.

Jackson, J. L., H. F. Gram, H. S. Ng, A. M. Pendergrass, and M. C. Pope, 1985. Safety Assessment of Accidental Radiological Releases: A Study Performed for the Conceptual Design of a Geologic Repository at Yucca Mountain, Nevada, Nuclear Safety, Vol. 26, No. 4, pp. 477-488.

Jackson, M. R., D. C. Noble, S. I. Weiss, L. T. Larson, and E. H. McKee, 1988. Timber Mountain Magmato-Thermal Event: An Intense Widespread Culmination of Magmatic and Hydrothermal Activity at the SW Nevada Volcanic Field, Annual Meeting Geological Society of America, Cordilleran Section, March 29-31, 1988, Las Vegas, Nevada, Abstracts with Programs, Vol. 20, p. 171.

Jones, R. B., 1989. Metals, The Nevada Mineral Industry 1988, Nevada Bureau of Mines & Geology Special Publication MI-1988, University of Nevada, Reno, pp. 9-18.

Jones, R. B., 1990. Metals, The Nevada Mineral Industry 1989, Nevada Bureau of Mines & Geology Special Publication MI-1989, University of Nevada, Reno, pp. 10-18.

Jones, R. B., 1991. Nevada, Annual Review 1990, Mining Engineering, May, 1991, pp. 503-504.

Jorgensen, D. J., J. W. Rankin, and J. Wilkins, Jr., 1989. The Geology, Alteration and Mineralogy of the Bullfrog Gold Deposit, Nye County, Nevada, American Institute of Professional Geologists, Northern Nevada Section, Field Trip, March 19, 20, 21, 1989, pp. 50-62.

Jorgensen, D. K., J. W. Rankin, and J. Wilkins, Jr., 1990. Geology, Alteration, and Mineralogy of Bond Gold's Bullfrog Deposit, Mining Engineering, July 1990, pp. 681-686.

Joyner, W. B., and D. M. Boore, 1982. Prediction of Earthquake Response Spectra, USGS-OFR-82-977, Open-File Report, U.S. Geological Survey, 14 pp.

Joyner, W. B., and D. M. Boore, 1988. Measurement Characterization and Prediction of Strong Ground Motion, in Earthquake Engineering and Soil Dynamics II Recent Advances in Ground Motion Evaluation, Geotechnical Special Publication 20, American Society of Civil Engineers, New York, pp. 43-102.

Kaplan, M. F., 1982. Archaeological Data as a Basis for Repository Marker Design, ONWI-354, Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, OH.

Kaplan, P.G., 1991. Using a GWTT Model to Identify Information Needs from Site Characterization, unpublished presentation to the Nuclear Waste Technical Review Board, May 20-21, 1991, Arlington, Virginia, Sandia National Laboratories, Albuquerque, NM.

Keener, W., 1986. Firm Brings Innovation to Great Basin, Western Oil World, August 1986.

Kemeny, J., and N. Cook, 1990. Rock Mechanics and Crustal Stress, Section 5, Demonstration of a Risk-Based Approach to High-Level Waste Repository Evaluation, EPRI NP-7057, Risk Engineering, Inc., Golden, CA.

Kensler, C. D., 1982. Survey of Historic Structures: Southern Nevada and Death Valley, JAB-00099-121, URS/John A. Blume & Associates, Engineers, San Francisco, CA.

Kerrisk, J. F., 1985. An Assessment of the Important Radionuclides Nuclear Waste, LA-10414-MS, Los Alamos National Laboratory, Los Alamos, NM.

Kerrisk, J. F., 1987. Groundwater Chemistry at Yucca Mountain, Nevada, and Vicinity, LA-10929-MS, Los Alamos National Laboratory, Los Alamos, NM.

Khoury, H. N., E. Salameh, and Q. Abdul-Jaber, 1985. Characteristics of an Unusual Highly Alkaline Water from the Maqarin Area, Northern Jordan, Journal of Hydrology, Vol. 81, pp. 79-91.

Kiciman, O. K., and N. A. Abrahamson, 1989. A Probabilistic Estimate of Seismic Damage to the Waste-Handling Building of a Repository Located at Yucca Mountain, Nevada, SAND88-7067C, Sandia National Laboratories, Albuquerque, NM.

King, J. L., G. A. Frazier, and T. A. Grant, 1989. Assessment of Faulting and Seismic Hazards at Yucca Mountain, Radioactive Waste Management and the Nuclear Fuel Cycle, Vol. 13, Nos. 1-4, pp. 155-170.

Kleinhampl, F. J., and J. I. Ziony, 1984. Mineral Resources of Northern Nye County, Nevada, Nevada Bureau of Mines & Geology Bulletin 99B, University of Nevada, Reno.

Knauss, K. G., 1987. Zeolitization of Glassy Topopah Spring Tuff Under Hydrothermal Conditions, in Scientific Basis for Nuclear Waste Management X, Materials Research Society Symposia Proceedings, December 1-4, 1986, Boston, Massachusetts, Vol. 84, Materials Research Society, Pittsburgh, PA, pp. 737-745.

Knauss, K. G., and T. J. Wolery, 1988. The Dissolution Kinetics of Quartz as a Function of pH and Time at 70 deg. C, Geochimica et Cosmochimica Acta, UCRL-96071, Vol. 52, No. 1, pp. 43-53.

Kohler, M., B. D. Honeyman, and J. O. Leckie, 1990. Neptunium(V) Sorption on Hematite (α-Fe_2O_3) in Aqueous Suspension: The Effect of Carbonate and EDTA, Yucca Mountain Project Monthly Activity Report, TWS-EES-13-11-90-066, Los Alamos National Laboratory, Los Alamos, NM, 39 pp.

Kral, V. E., 1951. Mineral Resources of Nye County, Nevada, University of Nevada Bulletin, Geology and Mining Series No. 50, Vol. 45, No. 3, Nevada State Bureau of Mines and the Mackay School of Mines, Reno, NV.

Kroitoru, L., A. Livnat, D. F. Fenster, and S. G. VanCamp, 1991. Origin of Carbonate Deposits in the Vicinity of Yucca Mountain, Nevada: Preliminary Results of Hydrochemical Modeling, AGU-MSA, Spring Meeting 1991 Program and Abstracts, Supplement to EOS, April 23, 1991, American Geophysical Union, Washington, DC, p. 116.

LANL (Los Alamos National Laboratory), 1991. Yucca Mountain Site Characterization Project, Monthly Activity Report, November, 1991, Los Alamos, NM.

Lahoud, R. G., D. H. Lobmeyer, and M. S. Whitfield, Jr., 1984. Geohydrology of Volcanic Tuff Penetrated by Test Well UE-25b#1, Yucca Mountain, Nye County, Nevada, USGS-WRI-84-4253, Water-Resources Investigations Report, U.S. Geological Survey.

Langbien, W. B., and S. A. Schumm, 1958. Yield of Sediment in Relation to Mean Annual Precipitation, Transactions, American Geophysical Union, Vol. 39, No. 6, pp. 1076-1084.

Lee, R. C., J. L. King, and T. A. Grant, 1991. Multiple Event Considerations for Postclosure Seismic Hazard Evaluations at Yucca Mountain, Nevada, in High Level Radioactive Waste Management, Proceedings of the Second Annual International Conference, Las Vegas, Nevada, April 28-May 3, 1991, Vol. 1, American Nuclear Society, Inc., La Grange Park, IL, pp. 76-82.

Leopold, L. B., W. W. Emmett, and R. M. Myrick, 1966. Channel and Hillslope Processes in a Semiarid Area, New Mexico, U.S. Geological Survey Professional Paper 352-G, U.S. Government Printing Office, Washington, DC, pp. 193-253.

Levy, M., and N. Christie-Blick, 1989. Pre-Mesozoic Palinspastic Reconstruction of the Eastern Great Basin (Western United States), Science, Vol. 245, pp. 1454-1462.

Levy, S. S., 1991. Mineralogic Alteration History and Paleohydrology at Yucca Mountain, Nevada, in High Level Radioactive Waste Management, Proceedings of the Second Annual International Conference, April 28-May 3, 1991, Las Vegas, Nevada, Vol. 1, American Nuclear Society, Inc., La Grange Park, Il., pp. 477-485.

Levy, S. S. and J. R. O'Neil, 1989. Moderate-Temperature Zeolitic Alteration in a Cooling Pyroclastic Deposit, Chemical Geology, Vol. 76, pp. 321-326.

Lin, W. and W. Daily, 1990. Hydrological Properties of Topopah Spring Tuff Under a Thermal Gradient - Laboratory Results, International Journal of Rock Mechanics, Mining Science, and Geomechanical Abstracts, Vol. 27, No. 5, pp. 373-386.

Lincoln, F. C., 1923. Mining Districts and Mineral Resources of Nevada, reprinted in 1982, Nevada Publications, Reno.

Linehan, J. J., 1991. Letter from J.J. Linehan (U.S. Nuclear Regulatory Commission) to D.E. Shelor (Office of Civilian Radioactive Waste Management), February 19, 1991; regarding five reports and four maps on natural resources.

Link, R. L., S. E. Logan, H. S. Ng, F. A. Rockenbach, and K. J. Hong, 1982. Parametric Studies of Radiological Consequences of Basaltic Volcanism, SAND81-2375, Sandia National Laboratories, Albuquerque, NM, 219 pp.

Lipman, P. W., and E. J. McKay, 1965. Geologic Map of the Topopah Spring SW Quadrangle, Nye County, Nevada, U.S. Geological Survey Quadrangle Map GQ-439, Scale 1:24,000, U.S. Geological Survey.

Lipman, P. W., R. L. Christiansen, and J. T. O'Connor, 1966. A Compositionally Zoned Ash-Flow Sheet in Southern Nevada, U.S. Geological Survey Professional Paper 524-F, U.S. Government Printing Office, Washington, DC.

Lockhard, D., 1989. Letter from D. Lockhard (Deputy Chief, Bureau of Mines) to J. Magruder (U.S. Department of Energy-Nevada), January 4, 1989; regarding Consultant (Mineral Surveillance) Services to the Department of Energy, Nevada Operations Office; First Quarter Report, October 1, 1988 - December 31, 1988.

Long, A., 1990. Climate and Net Infiltration at Yucca Mountain, Section 2, Demonstration of a Risk-Based Approach to High-Level Waste Repository Evaluation, EPRI NP-7057, Electric Power Research Institute, Palo Alto, CA.

Longsine, D. E., E. J. Bonano, and C. P. Harlan, 1987. User's Manual for the NEFTRAN Computer Code, SAND86-2405, Sandia National Laboratories, Albuquerque, NM.

Lowe, N. T., R. G. Raney, and J. R. Norberg, 1985. Principal Deposits of Strategic and Critical Minerals in Nevada, Information Circular 9.35, U.S. Bureau of Mines, Spokane, WA.

Luckey, R. R., 1990. Water-Level Monitoring to Characterize the Ground Water Flow System at Yucca Mountain, Nevada, Minimizing Risk to the Hydrological Environment, Spring Meeting American Institute of Hydrology, March 12-16, 1990, Las Vegas, Nevada, Program with Abstracts, American Institute of Hydrology, p. 22.

MLWA (Military Lands Withdrawal Acts), 1986. Military Lands Withdrawal Acts of 1986, Public Law 99-606, 100 Stat. 3457, Washington, DC.

Ma, C. W., S. J. Zavoshy, L. J. Jardine, and O. K. Kiciman, 1991. An Analysis of Scenarios and Potential Radiological Consequences Associated with U.S. Military Aircraft Crashes for the Yucca Mountain Repository, SAND90-7051, Sandia National Laboratories, Albuquerque, NM.

MacDougall, H. R. (comp.), 1985. Two-Stage Repository Development at Yucca Mountain: An Engineering Feasibility Study, SAND84-1351, Rev. 1, Sandia National Laboratories, Albuquerque, NM.

Maldonado, F., 1985. Late Tertiary Detachment Faults in the Bullfrog Hills, Southwestern Nevada, Abstract 74514, Annual Meeting Geological Society of America, October 28-31, 1985, Orlando, Florida, Abstracts with Programs, Vol. 17, No. 7, p. 651.

Maldonado, F., 1989. Stop 5: Detachment Faulting and Mineralization at Bullfrog Mountain, Bullfrog Hills Area, Geological Society of America 1989 Field Trip Guidebook, Special Publication Number 5, Missouri Department of Natural Resources, Rolla, MO, pp. 16-17.

Maldonado, F., 1990a. Geologic Map of the Northwest Quarter of the Bullfrog 15-Minute Quadrangle, Nye County, Nevada, Miscellaneous Investigations Series Map I-1985, U.S. Geological Survey.

Maldonado, F., 1990b. Structural Geology of the Upper Plate of the Bullfrog Hills Detachment Fault System, Southern Nevada, Geological Society of America Bulletin, Vol. 102, pp. 992-1006.

Maldonado, F., and B. P. Hausback, 1990. Geologic Map of the Northeast Quarter of the Bullfrog 15-Minute Quadrangle, Nye County, Nevada, Miscellaneous Investigations Series Map I-2049, U.S. Geological Survey.

Manning, P. A., T. G. Woehrle, and R. B. Burdick, 1990. Barnwell Ground Motion and Structural Response Measurements, UCRL-ID-103137, Lawrence Livermore National Laboratories, Livermore, CA, 88 pp.

Marshall, B. D., Z. E. Peterman, K. Futa, J. S. Stuckless, S. A. Mahan, J. S. Downey, and E. D. Gutentag, 1990. Origin of Carbonate Deposits in the Vicinity of Yucca Mountain, Nevada: Preliminary Results of Strontium-Isotope Analyses, in High Level Radioactive Waste Management, Proceedings of the International Topical Meeting, April 8-12, 1990, Las Vegas, Nevada, Vol. 2, American Nuclear Society, Inc., La Grange Park, IL, pp. 921-923.

Marshall, B. D., Z. E. Peterman, K. Futa, and J. S. Stuckless, 1991. Strontium Isotopes in Carbonate Deposits at Crater Flat, Nevada, in High Level Radioactive Waste Management, Proceedings of the Second Annual International Conference, April 28-May 3, 1991, Las Vegas, Nevada, Vol. 2, American Nuclear Society, Inc., La Grange Park, IL, pp. 1423-1428.

Martinez, M. J., 1985. FEMTRAN - A Finite Element Computer Program for Simulating Radionuclide Transport Through Porous Media, SAND84-0747, Sandia National Laboratories, Albuquerque, NM.

Martinez, M. J., 1988. Capillary-Driven Flow in a Fracture Located in a Porous Medium, SAND84-1697, Sandia National Laboratories, Albuquerque, NM, 52 pp.

Martinez, M. J., and R. C. Dykhuizen, 1988. Internal memorandum from M. J. Martinez and R. C. Dykhuizen to P. Kaplan, November 16, 1988, Sandia National Laboratories, Albuquerque, NM; regarding Apparent Permeability Across a Fracture: The Linear Case.

Martinez, M. J., and D. F. McTigue, 1991. The Distribution of Moisture Beneath a Two-Dimensional Surface Source, SAND90-0252, Sandia National Laboratories, Albuquerque, NM.

Mattson, S. R., 1988. Mineral Resource Evaluation: Implications of Human Intrusion and Interference on a High Level Nuclear Waste Repository, Waste Management '88, Proceedings of Annual Symposium, February 28-March 3, 1988, Tucson, AZ, Vol. 2, pp. 915-924.

Mattson, S. R., 1989. Mineral and Energy Resources of the Yucca Mountain Region, Geological Society of America 1989 Field Trip Guidebook, Special Publication Number 5, Missouri Department of Natural Resources, Rolla, MO, pp. 29-30.

Mattson, S. R., 1991. Internal letter from S. R. Mattson to J. L. Younker, July 9, 1991, Science Applications International Corporation, Technical & Management Support Services, Las Vegas, Nevada; regarding wildcat drilling in and near the southwestern Nevada volcanic field.

Mattson, S. R., and A. C. Matthusen, 1992. Internal memorandum from S. R. Mattson and A. C. Matthusen to J. L. Younker, January 17, 1992, Science Applications International Corporation, Las Vegas, Nevada; regarding Literature Review for the Human Interference Guideline Section of the Early Site Suitability Evaluation.

Mattson, S. R., B. R. Judd, S. R. Sinnock, and D. T. Hoxie, 1991. Testing Priorities at Yucca Mountain: Recommended Early Tests to Detect Potentially Unsuitable Conditions for a Nuclear Waste Repository, YMP/91-25, 2 volumes, Yucca Mountain Site Characterization Project, Las Vegas, NV.

McArthur, R. D., and N. R. Burkhard, 1986. Geological and Geophysical Investigations of Mid Valley, UCID-20740, Lawrence Livermore National Laboratory, Livermore, CA.

McDaniel, S., 1985. Small Methane Pockets Found in Nevada, Western Oil World, Vol. 42, No. 5, p. 15.

McGuire, R. K., and R. A. Shaw, 1991. HLW Repository Performance Assessment Sensitivities, Letter Report, Electric Power Research Institute, Palo Alto, CA.

McGuire, R. K., D. B. Bullen, N. Cook, K. J. Coppersmith, J. Kemeny, A Long, F. J. Pearson, Jr., F. Schwartz, M. Sheridan, R. R. Youngs, 1990. Demonstration of a Risk-Based Approach to High-Level Repository Evaluation, NP-7057, Electric Power Research Institute, Palo Alto, CA.

McKague, H. L., P. P. Orkild, and S. R. Mattson, 1989. The Geology of the Nevada Test Site and Surrounding Area, Clark and Nye Counties, Nevada, July 5-7, 1989, American Geophysical Union Field Trip Guidebook T186, Washington, DC.

McKee, E. H., 1979. Ash-Flow Sheets and Calderas: Their Genetic Relationship to Ore Deposits in Nevada, Ash-Flow Tuffs, C.E. Chapin and W.E. Elston (eds.), Geological Society of America Special Paper 180, Boulder, CO, pp. 205-211.

McKee, E. H., D. C. Noblé, and S. I. Weiss, 1990. Late Neogene Volcanism and Tectonism in the Goldfield Segment of the Walker Lane Belt, Annual Meeting Geological Society of America, Cordilleran Section, March 14-16, 1990, Tucson, AZ, Abstracts with Programs, Vol. 22, No. 3.

McKee, R. W., H. D. Huber, K. I. Johnson, and M. C. Bierschbach, 1991. Effects of Spent Fuel Aging on Repository Disposal Requirements, in High Level Radioactive Waste Management, Proceedings of the Second Annual International Conference, April 28-May 3, 1991, Las Vegas, Nevada, Vol. 2, American Nuclear Society, Inc., La Grange Park, IL, pp. 1132-1142.

McNatt, R. M., 1990. Letter from R. M. McNatt (U.S. Fish and Wildlife Service) to C. P. Gertz (U.S. Department of Energy, Nevada), February 9, 1990; regarding the U.S. Fish and Wildlife Service Consultation and Biological Opinion on the potential for adverse impacts on the desert tortoise from site characterization planned activities.

Means, J. L., D. A. Crerar, M. P. Borcsik and J. O. Duguid, 1978. Adsorption of Co and Selected Actinides by Mn and Fe Oxides in Soils and Sediments, Geochimica et Cosmochimica Acta, Vol. 42, No. 12, pp. 1763-1773.

Meijer, A., 1990. Yucca Mountain Project Far-Field Sorption Studies and Data Needs, LA-11671-MS, Los Alamos National Laboratory, Los Alamos, NM.

Meijer, A., I. Triay, S. Knight, and M. Cisneros, 1989. Sorption of Radionuclides on Yucca Mountain Tuffs, in FOCUS '89, Proceedings of the Topical Meeting on Nuclear Waste Isolation in the Unsaturated Zone, September 17-21, 1989, Las Vegas, Nevada, American Nuclear Society, La Grange Park, IL.

Meike, A., and W. Glassley, 1989. In-Situ Observation of the Alpha/Beta Cristobalite Transition Using High Voltage Electron Microscopy, UCRL-101323, preprint, Lawrence Livermore National Laboratory, Livermore, CA.

Molinari, M. P., 1984. Late Cenozoic Geology and Tectonics of Stewart and Monte Cristo Valleys, West-Central Nevada, unpublished M.S. thesis, University of Nevada, Reno, 124 pp.

Monsen, S. A., M. D. Carr, M. C. Reheis, and P. P. Orkild, 1990. Geologic Map of Bare Mountain, Nye County, Nevada, U.S. Geological Survey Open-File Report 90-25, Scale 1:24,000, U.S. Geological Survey.

Montazer, P., and W. E. Wilson, 1984. Conceptual Hydrologic Model of Flow in the Unsaturated Zone, Yucca Mountain, Nevada, USGS-WRI-84-4345, Water-Resources Investigations Report, U.S. Geological Survey.

Morales, A. R. (comp.), 1985. Technical Correspondence in Support of the Final Environmental Assessment, SAND85-2509, Sandia National Laboratories, Albuquerque, NM.

Morrison, R. B., 1967. Principles of Quaternary Soil Stratigraphy, in Quaternary Soils, Proceeding of the International Association of Quaternary Research 7th Congress, Vol. 9, pp. 1-69.

Mountain West Research, 1989. Yucca Mountain Socioeconomic Project An Interim Report on the State of Nevada Socioeconomic Studies, NWPO-SE-022-89, State of Nevada Agency for Nuclear Projects/Nuclear Waste Project Office, Reno, NV.

Mualem, Y., 1976. A New Model for Predicting the Hydraulic Conductivity of Unsaturated Porous Materials, Water Resources Research, Vol. 12, No. 3, pp. 513-522.

Muir Wood, R., and G. C. P. King, 1991a. An Empirical Data Base for the Investigation of Earthquake-Related Changes in Crustal Hydrology, in High Level Radioactive Waste Management, Proceedings of the Second Annual International Conference, April 28-May 3, 1991, Las Vegas, Nevada, Vol. 2, American Nuclear Society, Inc., La Grange Park, IL, pp. 1284-1290.

Muir Wood, R., and G. C. P. King, 1991b. Hydrological Signatures of Earthquake Strain, Program Spring Meeting 1991, American Geophysical Union and Mineralogical Society of America, May 28-31, 1991, Baltimore, MD, p. 102.

Muller, D. C., and J. E. Kibler, 1984. Preliminary Analysis of Geophysical Logs from Drill Hole UE-25p#1, Yucca Mountain, Nye County, Nevada, USGS-OFR-84-649, Open-File Report, U.S. Geological Survey, 14 pp.

Myers, G. L., and L. D. Meinert, 1991. Alteration, Mineralization, and Gold Distribution in the Fortitude Gold Skarn, in Geology and Ore Deposits of the Great Basin, Symposium Proceedings, Vol. 1, G. L. Raines, R. E. Lisle, R. W. Schafer, and W. H. Wilkinson (eds.), April 1-5, 1990, Geological Society of Nevada, Reno, pp. 407-417.

Myers, W. B., 1987. Detachment of Tertiary Strata from Their Paleozoic Floor near Mercury, Nevada, Annual Meeting Geological Society of America, October 26-29, 1987, Phoenix, Arizona, Abstracts with Programs, Vol. 19, No. 7, p. 783.

NBMG (Nevada Bureau of Mines and Geology), 1988. Petroleum Exploration and Production in Nevada, Nevada Geology, Quarterly Newsletter, Winter, 1988.

NBMG (Nevada Bureau of Mines and Geology), 1990. Active Mines in Nevada, Nevada Geology, Quarterly Newsletter, Summer, 1990.

NDM-NBMG (Nevada Department of Minerals-Nevada Bureau of Mines and Geology), 1991. Major Mines of Nevada 1990, Nevada Bureau of Mines and Geology Special Publication 11, University of Nevada, Reno.

NEPA (National Environmental Policy Act), 1969. Public Law 91-190, 42 U.S.C. 4341 et seq., Amended by Public Laws 94-52 and 94-83, Washington, DC.

NHPA (National Historic Preservation Act), 1966. Public Law 89-665, 80 STAT. 915, 16 U.S.C. 470 et seq., Amended by Public Laws 91-243, 93-54, 94-422, 94-458, 96-199, 96-244, and 96-515, Washington, DC.

NRC (U.S. Nuclear Regulatory Commission), 1989. Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material, Regulatory Guide 7.8, Rev. 1, Washington, DC.

NRC (U.S. Nuclear Regulatory Commission), 1990. Phase I Demonstration of the Nuclear Regulatory Commission's Capability to Conduct a Performance Assessment for a HLW Repository, U.S. Nuclear Regulatory Commission final draft report, Washington, DC.

NWPA (Nuclear Waste Policy Act), 1983. Nuclear Waste Policy Act of 1982, Public Law 97-425, 42 U.S.C. 10101-10226, Washington, DC.

NWPAA (Nuclear Waste Policy Act Amendments), 1987. Amendments to the Nuclear Waste Policy Act of 1982 - Public Law 100-203 - December 22, 1987, 100th Congress, Title V, pp 236-266, Washington, DC.

Narasimhan, T. N., and J. S. Y. Wang, 1990. Conceptual, Experimental, and Computational Approaches to Support Performance Assessment of Hydrology and Chemical Transport at Yucca Mountain, SAND89-7018, Sandia National Laboratories, Albuquerque, NM.

Nathenson, M., and M. Guffanti, 1988. Geothermal Gradients in the Conterminous United States, Journal of Geophysical Research, Vol. 93, No. B6, pp. 6437-6450.

National Research Council, 1988. Probabilistic Seismic Hazard Analysis, DOE-ER/12018--T7, National Academy Press, Washington, DC.

National Research Council, 1990. Ground Water Models, Scientific and Regulatory Applications, National Academy Press, Washington, DC.

Naumann, T. R., D. L. Feuerbach, and E. I. Smith, 1991. Structural Control of Pliocene Volcanism in the Vicinity of the Nevada Test Site, Nevada: An Example from Buckboard Mesa, Annual Meeting Geological Society of America, Cordilleran Section, March 25-27, 1991, San Francisco, California, Abstracts with Programs, Vol. 23, No. 2, p. 82.

Neal, C., and G. Stanger, 1984. Calcium and Magnesium Hydroxide Precipitation from Alkaline Groundwaters in Oman, and Their Significance to the Process of Serpentinization, Mineralogical Magazine, Vol. 48, pp. 237-241.

Neal, J. T., 1986. Preliminary Validation of Geology at Site for Repository Surface Facilities, Yucca Mountain, Nevada, SAND85-0815, Sandia National Laboratories, Albuquerque, NM.

Neilands, J. B., 1974. Microbial Iron Metabolism, Academic Press, NY., 547 pp.

Neilands, J. B., 1981. Microbial Iron Compounds Annual Review Biochemistry, Vol. 50, pp. 715-731.

Neretnieks, I., 1980. Diffusion in the Rock Matrix: An Important Factor in Radionuclide Retardation?, Journal of Geophysical Research, Vol. 85, No. B8, pp. 4379-4397.

Neretnieks, I., and A. Rasmuson, 1984. An Approach to Modelling Radionuclide Migration in a Medium with Strongly Varying Velocity and Block Sizes Along the Flow Path, Water Resources Research, Vol. 20, No. 12, pp. 1823-1836.

Newton, T. W., D. E. Hobart, and P. D. Palmer, 1986. The Formation of Pu(IV)-Colloid by the Alpha-reduction of Pu(V) or Pu(VI) in Aqueous Solutions, Radiochemica Acta, Vol. 39, pp. 139-147.

Nicholson, T. J., P. J. Wierenga, G. W. Gee, E. A. Jacobson, D. J. Polmann, D. B. McLaughlin, and L. W. Gelhar, 1987. Validation of Stochastic Flow and Transport Models for Unsaturated Soils: Field Study and Preliminary Results, in Proceedings of the Conference on Geostatistical, Sensitivity, and Uncertainty Methods for Ground-Water Flow and Radionculide Transport Modeling, DOE/AECL, pp. 275-296.

Niemi, A., and G. S. Bodvarsson, 1988. Preliminary Capillary Hysteresis Simulations in Fractured Rocks, Yucca Mountain, Nevada, Journal of Contaminant Hydrology, Vol. 3, pp. 277-291.

Nimick, F. B., 1990a. The Thermal Conductivity of Seven Thermal/Mechanical Units at Yucca Mountain, Nevada, SAND88-1387, Sandia National Laboratories, Albuquerque, NM.

Nimick, F. B., 1990b. The Thermal Conductivity of the Topopah Spring Member at Yucca Mountain, Nevada, SAND86-0090, Sandia National Laboratories, Albuquerque, NM.

Nimick, F. B., R. G. Van Buskirk, and A. F. McFarland, 1987. Uniaxial and Triaxial Compression Test Series on the Topopah Spring Member from USW G-2, Yucca Mountain, Nevada, SAND85-0703, Sandia National Laboratories, Albuquerque, NM.

Nitao, J. J., 1988. Numerical Modeling of the Thermal and Hydrological Environment Around a Nuclear Waste Package Using the Equivalent Continuum Appromixation: Horizontal Emplacement, UCID-21444, Lawrence Livermore Laboratory, Livermore, CA.

Nitao, J. J., 1991. Theory of Matrix and Fracture Flow Regimes in Unsaturated, Fractured Porous Media, UCRL-JC-104933, preprint, Lawrence Livermore National Laboratory, Livermore, CA.

Nitao, J., and T. Buscheck, 1989. On the Infiltration of a Liquid Front in an Unsaturated, Fractured Porous Medium, UCRL-100777, Lawrence Livermore National Laboratory, Livermore, CA.

Nitao, J. J., and T. A. Buscheck, 1991. Infiltration of a Liquid Front in an Unsaturated, Fractured Porous Media, UCRL-JC-107092, Lawrence Livermore Laboratory, Livermore, CA.

Nitsche, H., 1991. Basic Research for Assessment of Geologic Nuclear Waste Repositories: What Solubility and Speciation Studies of Transuranium Elements Can Tell Us, in Scientific Basis for Nuclear Waste Management XIV, Materials Research Society Symposium Proceedings, Vol. 212, Materials Research Society, Pittsburgh, Penn., pp. 517-529.

Nitsche, H., R. C. Gatti, and S. C. Lee, 1991. Low-Level Determination of Plutonium by Gamma and L-Xray Spectroscopy, in Proceedings of the International Topical Conference on Methods and Applications of Radioanalytical Chemistry, Vol. 11, in press.

Noble, D. C., S. I. Weiss, and E. H. McKee, 1991. Magmatic and Hydrothermal Activity, Caldera Geology, and Regional Extension in the Western Part of the Southwestern Nevada Volcanic Field, in Geology and Ore Deposits of the Great Basin Symposium Proceedings, Vol. 2, G. L. Raines, R. E. Lisle, R. W. Schafer, and W. H. Wilkinson (eds.), April 1-5, 1990, Geological Society of Nevada, Reno, pp. 913-934.

Norris, A. E., 1989. The Use of Chlorine Isotope Measurements to Trace Water Movements at Yucca Mountain, in FOCUS '89, Proceedings of the Topical Meeting on Nuclear Waste Isolation in the Unsaturated Zone, September 17-21, 1989, Las Vegas, Nevada, American Nuclear Society, La Grange Park, IL.

Oliver, H. W., D. A. Ponce, and R. F. Sikora, 1991. Major Results of Gravity and Magnetic Studies at Yucca Mountain, Nevada, in Proceedings of the Second Annual International Conference on High Level Radioactive Waste Management, April 28-May 3, 1991, Las Vegas, Nevada, Vol. 1, American Nuclear Society, La Grange Park, Il, pp. 787-794.

Olofsson, U., B. Allard, K. Andersson, and B. Torstenfelt, 1981. Formation and Properties of Radiocolloids in Aqueous Solution--A Literature Survey, National Council for Radioactive Waste Report Prav 4.25, Programradet for Radioaktivtavfall, Stockholm, Sweden.

Olofsson, U., B. Allard, K. Andersson, and B. Torstenfelt, 1982a. Formation and Properties of Americium Colloids in Aqueous Systems, in Scientific Basis for Nuclear Waste Management IV, Materials Research Society Symposia Proceedings, Boston, Massachusetts, November 1981, S. Topp (ed.), Vol. 6, North-Holland, Elsevier Science Publishing Co., Inc., NY, pp. 191-198.

Olofsson, U., B. Allard, B. Torstenfelt, and K. Andersson, 1982b. Properties and Mobilities of Actinide Colloids in Geologic Systems, in Scientific Basis for Nuclear Waste Management V, Materials Research Society Symposia Proceedings, Berlin, Germany, June 7-10, 1982, W. Lutze (ed.), Vol. 5, North-Holland, Elsevier Science Publishing Co., Inc., NY, pp. 755-764.

Olsson, W. A., 1987. Rock Joint Compliance Studies, SAND86-0177, Sandia National Laboratories, Albuquerque, NM.

Olsson, W. A., 1988. Compliance and Strength of Artificial Joints in Topopah Spring Tuff, SAND88-0660, Sandia National Laboratories, Albuquerque, NM.

Olsson, W. A., and A. K. Jones, 1980. Rock Mechanics Properties of Volcanic Tuffs from the Nevada Test Site, SAND80-1453, Sandia National Laboratories, Albuquerque, NM.

O'Neill, J. M., J. W. Whitney, and M. R. Hudson, 1991. Strike-Slip Faulting and Oroclinal Bending at Yucca Mountain, Nevada: Evidence from Photogeologic and Kinematic Analysis, Annual Meeting Geological Society of America, San Diego, California, October 21-24, 1991, Abstracts with Programs, Vol. 23, No. 5, p. A119.

Ortiz, T. S., R. L. Williams, F. B. Nimick, B. C. Whittet, and D. L. South, 1985. A Three-Dimensional Model of Reference Thermal/Mechanical and Hydrological Stratigraphy at Yucca Mountain, Southern Nevada, SAND84-1076, Sandia National Laboratories, Albuquerque, NM.

Ostler, W. K., 1991. Biological Resource Concerns, Presentation to the Nuclear Waste Technical Review Board, October 8-10, 1991, Las Vegas, NV.

Oversby, V. M., 1987. Important Radionuclides in High Level Nuclear Waste Disposal: Determination Using a Comparison of the U.S. EPA and NRC Regulations, Nuclear and Chemical Waste Management, Vol. 7, pp. 149-161.

Owen, G. N., P. I. Yanev, and R. E. Scholl, 1980. Considerations for Developing Seismic Design Criteria for Nuclear Waste Storage Repositories, JAB-00099-128, URS/John A. Blume & Associates, Engineers, San Francisco, CA.

Park, U., and C. G. Pflum, 1990. Requirements for Controlling a Repository's Releases of Carbon-14 Dioxide; the High Costs and Negligible Benefits, in High Level Radioactive Waste Management, Proceedings of the International Topical Meeting, April 8-12, 1990, Las Vegas, Nevada, Vol. 2, American Nuclear Society, Inc., La Grange Park, IL, pp. 1158-1164.

Parker, G. J., W. P. McCaughey, Jr., and M. A. Lugo, 1991. Regulatory Issues Impacting the U.S. High-Level Radioactive Waste Management Program, in High Level Radioactive Waste Management, Proceedings of the Second International Conference, Las Vegas, Nevada, April 28-May 3, 1991, Vol. 1, American Nuclear Society, Inc., La Grange Park, IL., pp. 12-18.

Peck, J. H., U. S. Clanton, C. A. Rautman, R. W. Spendler, and D. Vaniman, 1991. Letter from J. H. Peck, U. S. Clanton, C. A. Rautman, R. W. Spendler, and D. Vaniman to D. C. Dobson and J. R. Dyer, May 15, 1991; regarding Core Evaluation to Determine Contacts Between Thermal-Mechanical Units TSw1 and TSw2.

Perkins, D. M., P. C. Thenhaus, S. L. Hanson, and S. T. Algermissen, 1986. A Reconnaissance Assessment of Probabilistic Earthquake Accelerations at the Nevada Test Site, USGS-OFR-87-199, Open-File Report, U.S. Geological Survey. 18 pp.

Perry, F. V., and B. M. Crowe, 1990. Polycyclic Volcanism and Waning Magmatism at a Small-Volume Volcanic Field, Crater Flat, Nevada, EOS, Transactions, American Geophysical Union, Vol. 71, No. 43, p. 1683.

Peters, R. R., and E. A. Klavetter, 1988. A Continuum Model for Water Movement in an Unsaturated Fractured Rock Mass, Water Resources Research, Vol. 24, No. 3, pp. 416-430.

Petersen, M. A., and B. A. Ahler, 1990. Geology of the Bullfrog Gold Deposit, Nye County, Nevada, Geological Society of Nevada Newsletter, November, 1990.

Peterson, F. F., 1988. Consultant's Report: Soil-Geomorphology Studies in the Crater Flat, Nevada, Area, Appendix B of Quaternary Geology and Active Faulting at and near Yucca Mountain, Task 1 Final Report, January 1, 1987-June 30, 1988, in Evaluation of the Geologic Relations and Seismotectonic Stability of the Yucca Mountain Area, Nevada Nuclear Waste Site Investigation (NNWSI). Center for Neotectonic Studies, Mackay School of Mines, University of Nevada, Reno.

Peterson, J. A., 1988. Eastern Great Basin and Snake River Downwarp, Geology and Petroleum Resources, USGS-OFR-88-450-H, draft, Open-File Report, U.S. Geological Survey.

Phillips, J. S., and B. A. Luke, 1991. Tunnel Damage Resulting from Seismic Loading, SAND90-1721C, preprint, Sandia National Laboratories, Albuquerque, NM.

Phillips, J. S., M. C. Walck, and L. E. Shephard, 1991. Weapons Test Seismic Investigations at Yucca Mountain, in High Level Radioactive Waste Management, Proceedings of the Second Annual International Conference, April 28-May 3, 1991, Las Vegas, Nevada, Vol. 1, American Nuclear Society, Inc., La Grange Park, IL, pp. 83-90.

Pippin, L. C. (ed.), 1984. Limited Test Excavations at Selected Archaeological Sites in the NNWSI Yucca Mountain Project Area, Southern Nye County, Nevada, Social Sciences Technical Report No. 40, Desert Research Institute, University of Nevada System, Las Vegas.

Pippin, L. C., 1986. An Overview of Cultural Resources on Pahute and Rainier Mesas on the Nevada Test Site, Nye County, Nevada, Desert Research Institute Technical Report Series No. 45,draft, University of Nevada System, Reno, pp. 1-8, 55-70.

Pippin L. C., and D. L. Zerga, 1981a. An Annotated Bibliography of Cultural Resources Literature for the Nevada Nuclear Waste Storage Investigations, Technical Report Number 30, Desert Research Institute, University of Nevada System, Reno.

Pippin, L. C., and D. L. Zerga, 1981b. Cultural Resources Overview for the Nevada Nuclear Waste Storage Investigations, Nevada Test Site, Nye County, Nevada, Technical Report Number 24, Desert Research Institute, University of Nevada System, Reno.

Pippin, L. C., R. L. Clerico, and R. L. Reno, 1982. An Archaeological Reconnaissance of the NNWSI Yucca Mountain Project Area, Southern Nye County, Nevada, Social Sciences Center Publication No. 28, Desert Research Institute, University of Nevada System, Reno.

Poole, F. G., and G. E. Claypool, 1984. Petroleum Source-Rock Potential and Crude-Oil Correlation in the Great Basin, Hydrocarbon Source Rocks of the Greater Rocky Mountain Region, J. Woodward, F. F. Meissner, and J. L. Clayton (eds.), Rocky Mountain Association of Geologists, Denver, CO, pp. 179-229.

Poole, F. G., G. E. Claypool, and T. D. Fouch, 1983. Major Episodes of Petroleum Generation in Part of the Northern Great Basin, Geothermal Resources Council, Special Report No. 13, pp. 207-213.

Pratt, H. R., W. A. Hustrulid, and D. E. Stephenson, 1978. Earthquake Damage to Underground Facilities, DP-1513, E. I. du Pont de Nemours & Co., Aiken, SC.

Price, J. G., 1988. Letter from J. G. Price (University of Nevada, Reno) to C. Gertz (U.S. Department of Energy, Nevada) October 25, 1988; regarding the geology and mineral resource of Nevada.

Price, J. G., 1989. Summary, The Nevada Mineral Industry 1988, Nevada Bureau of Mines & Geology Special Publication MI-1988, University of Nevada, Reno, pp. 3-7.

Price, J. G., 1990. Summary, The Nevada Mineral Industry 1989, Nevada Bureau of Mines & Geology Special Publication MI-1989, University of Nevada, Reno, pp. 3-9.

Price, J. G., S. T. Conlon, C. D. Henry, 1987. Tectonic Controls on Orientation and Size of Epithermal Veins, presented at North American Conference on Tectonic Control of Ore Deposits, October 6, 1987, Rolla, MO.

Price, R. H., 1986. Effects of Sample Size on the Mechanical Behavior of Topopah Spring Tuff, SAND85-0709, Sandia National Laboratories, Albuquerque, NM.

Price, R. H., J. R. Connolly, and K. Keil, 1987. Petrologic and Mechanical Properties of Outcrop Samples of the Welded, Devitrified Topopah Spring Member of the Paintbrush Tuff, SAND86-1131, Sandia National Laboratories, Albuquerque, NM.

Prindle, R. W., and P. L. Hopkins, 1990. On Conditions and Parameters Important to Model Sensitivity for Unsaturated Flow Through Layered, Fractured Tuff: Results of Analyses for HYDROCOIN Level 3 Case 2, SAND89-0652, Sandia National Laboratories, Albuquerque, NM.

Proffett, J. M., Jr., 1977. Cenozoic Geology of the Yerington District, Nevada, and Implications for the Nature and Origin of Basin and Range Faulting, Geological Society of America Bulletin, Vol. 88, No. 2, pp. 247-266.

Pruess, K., 1987. TOUGH User's Guide, NUREG/CR-4645, SAND86-7104, LBL-20700, U.S. Nuclear Regulatory Commission, Washingtion, DC.

Pruess, K., and T. N. Narasimhan, 1985. A Practical Method for Modeling Fluid and Heat Flow in Fractured Porous Media, Society of Petroleum Engineers Journal, pp. 14-26.

Pruess, K., and J. S. Y. Wang, 1987. Numerical Modeling of Isothermal and Nonisothermal Flow in Unsaturated Fractured Rock - A Review, Flow and Transport Through Unsaturated Fractured Rock, Geophysical Monograph 42, American Geophysical Union, Washington, DC, pp. 11-21.

Purcell, C., 1986. Potential Erosion at the Yucca Mountain Nuclear Waste Site, NRC FIN A0294, draft, Lawrence Livermore National Laboratory, Livermore, CA.

Purcell, C., 1986, revised. Potential Erosion at the Yucca Mountain Nuclear Waste Site, FIN A0297, revised, Lawrence Livermore National Laboratory, Livermore, CA.

Purcell, C., 1988. Geomorphic Evaluation of Proposed Shaft and Ramp Locations Yucca Mountain High Level Waste Site, LLNL/NRC-NNWSI-CRP-87/88-YM1, draft, Lawrence Livermore National Laboratory, Livermore, CA.

Purkey, B. W., 1989. Oil and Gas, The Nevada Mineral Industry 1988, Nevada Bureau of Mines & Geology Special Publication MI-1988, University of Nevada, Reno, pp. 45-52.

Purkey, B. W., 1990. Oil and Gas, The Nevada Mineral Industry 1989, Nevada Bureau of Mines & Geology Special Publication MI-1989, University of Nevada, Reno, pp. 44-50.

Quade, J., 1986. Late Quaternary Environmental Changes in the Upper Las Vegas Valley, Nevada, Quaternary Research, Vol. 26, pp. 340-357.

Quade, J., and T. E. Cerling, 1990. Stable Isotopic Evidence for a Pedogenic Origin of Carbonates in Trench 14 near Yucca Mountain, Nevada, Science, Vol. 250, pp. 1549-1552.

Quade, J., and W. L. Pratt, 1989. Late Wisconsin Groundwater Discharge Environments of the Southwestern Indian Springs Valley, Southern Nevada, Quaternary Research, Vol. 31, pp. 351-370.

Quade, J., and J. V. Tingley, 1983. A Mineral Inventory of the Nevada Test Site, and Portions of Nellis Bombing and Gunnery Range, Southern Nye County, Nevada, DOE/NV/10295-1, U.S. Department of Energy, Nevada Operations Office, Las Vegas, NV.

Raloff, J., 1990. The Colloid Threat, Science News, March 17, 1990, Vol. 137, pp. 169-170.

Ramelli, A. R., J. W. Bell, and C. M. dePolo, 1988. Evidence for Distributive Faulting at Yucca Mountain, Nevada, Centennial Celebration Geological Society of America, October 31-November 3, 1988, Denver, Colorado, Abstracts with Programs, Vol. 20, p. A383.

Ramelli, A. R., T. L. Sawyer, J. W. Bell, C. M. dePolo, F. F. Peterson, and R. I. Dorn, 1989. Preliminary Analysis of Fault and Fracture Patterns at Yucca Mountain, Southern Nevada, in FOCUS '89, Proceedings of the Topical Meeting on Nuclear Waste Isolation in the Unsaturated Zone, September 17-21, 1989, Las Vegas, Nevada, American Nuclear Society, La Grange Park, IL, pp. 336-343.

Raney, R. G., 1988a. Ash-Flow Sheets and Calderas: Their Relationship to Ore Deposits in Nevada, by E. H. McKee--A Review of the Paper and of Its Application in an Assessment of the Resource Potential at a Proposed High-Level Waste Repository, Yucca Mountain, Nye County, Nevada, NRC FIN D1018, Office of Nuclear Material and Safeguards, U.S. Nuclear Regulatory Commission, Washington, DC.

Raney, R. G., 1988b. Reported Effects of Selected Earthquakes in the Western North American Intermontane Region, 1852-1983, on Underground Workings and Local and Regional Hydrology: A Summary, NRC FIN D1018,Office of Nuclear Material and Safeguards, U.S. Nuclear Regulatory Commission, Washington, DC.

Raney, R. G., 1989. Mines, Prospects, and Mineral Locations in Clark, Esmeralda, Lincoln, and Nye Counties, Nevada, Inyo County, California, and Portions of Mono and San Bernardino Counties, California, NRC FIN D1018, Office of Nuclear Material and Safeguards, U.S. Nuclear Regulatory Commission, Washington, DC.

Raney, R. G., 1990. Active Mines and Prospects within a Thirty-Mile Radious of the Proposed High-Level Repository Site at Yucca Mountain, Nye County, Nevada, Subsequent to January 1988 (As of July 1990), NRC FIN D1018, U.S. Nuclear Regulatory Commission, Washington, DC.

Ransome, F. L., 1907. Preliminary Account of Goldfield, Bullfrog, and Other Mining Districts in Southern Nevada, U.S. Geological Survey Bulletin 303, Reprinted as F. L. Ransome, 1983. "Mines of Goldfield, Bullfrog and Other Southern Nevada Districts," Nevada Publications, Las Vegas.

Rasmussen, T. C., and D. D. Evans, 1987. Unsaturated Flow and Transport Through Fractured Rock Related to High-Level Waste Repositories, Phase II, NUREG/CR-4655, U.S. Nuclear Regulatory Commission, Washington, DC.

Rautman, C. A., 1985. Internal letter from C. A. Rautman to S. Sinnock, December 11, 1985, Sandia National Laboratories, ALbuquerque, NM; regarding Potential Problems with Topopah Spring Stratigraphy.

Read, D. L., and W. D. Zogg, 1988. Description and Origin of the Devonian Dolomite Oil Reservoir, Grant Canyon Field, Nye County, Nevada, Carbonate Symposium, Rocky Mountain Association of Geologists, pp. 229-240.

Reed, D. T., and R. A. Van Konynenburg, 1987. Effect of Ionizing Radiation on Moist Air Systems, UCRL-97936, preprint Lawrence Livermore National Laboratory, Livermore, CA.

Reheis, M. C., 1988. Preliminary Study of Quaternary Faulting on the East Side of Bare Mountain, Nye County, Nevada, Geologic and Hydrologic Investigations of a Potential Nuclear Waste Disposal Site at Yucca Mountain, Southern Nevada, M. D. Carr and J. C. Yount (eds.), U.S. Geological Survey Bulletin 1790, pp. 103-111.

Reno, R. L., G. H. Henton, L. C. Pippin, and C. L. Lockett, 1989. Miscellaneous Data Recovery Studies at Yucca Mountain, Technical Report Number 59, Desert Research Institute, University of Nevada System, Reno.

Robinson, B. A., 1990. Internal memorandum from B. H. Robinson to distribution, June 29, 1990, Los Alamos National Laboratory, Los Alamos, NM; regarding A Conceptual Model for Radionuclide Migration in the Saturated Zone.

Robison, J. H., 1984. Ground-Water Level Data and Preliminary Potentiometric-Surface Maps, Yucca Mountain and Vicinity, Nye County, Nevada, USGS-WRI-84-4197, Water-Resources Investigations Report, U.S. Geological Survey.

Robison, J. H., D. M. Stephens, R. R. Luckey, and D. A. Baldwin, 1988. Water Levels in Periodically Measured Wells in the Yucca Mountain Area, Nevada, 1981-87, USGS-OFR-88-468, Open-File Report, U.S. Geological Survey.

Rockhold, M. L., B. Sagar, and M. P. Connelly, 1990. Multi-Dimensional Modeling of Unsaturated Flow in the Vicinity of Exploratory Shafts and Fault Zones at Yucca Mountian, Nevada, in High Level Radioactive Waste Management, Proceedings of the International Topical Meeting, April 8-12, 1990, Las Vegas, Nev., Vol. 2, American Nuclear Society, Inc., La Grange Park, IL, pp. 1192-1198.

Rogers, A. M., D. M. Perkins, and F. A. McKeown, 1976. A Catalog of Seismicity within 400 km of the Nevada Test Site, USGS-OFR-76-832, Open-File Report, U.S. Geological Survey.

Rogers, A. M., D. M. Perkins, and F. A. McKeown, 1977. A Preliminary Assessment of the Seismic Hazard of the Nevada Test Site Region, Bulletin of the Seismological Society of America, Vol. 67, No. 6, pp. 1587-1606.

Rogers, A. M., S. C. Harmsen, W. J. Carr, and W. Spence, 1983. Southern Great Basin Seismological Data Report for 1981 and Preliminary Data Analysis, USGS-OFR-83-669, Open-File Report, U.S. Geological Survey.

Rogers, A. M., S. C. Harmsen, R. B. Herrmann, and M. E. Meremonte, 1987a. A Study of Ground Motion Attenuation in the Southern Great Basin, Nevada-California, Using Several Techniques for Estimates of Qs, log Ao, and Coda Q, Journal of Geophysical Research, Vol. 92, No. B5, pp. 3527-3540.

Rogers, A. M., S. C. Harmsen, and M. E. Meremonte, 1987b. Evaluation of the Seismicity of the Southern Great Basin and Its Relationship to the Tectonic Framework of the Region, USGS-OFR-87-408, draft Open-File Report, U.S. Geological Survey.

Rogers, K., 1991. Study Says Nuke Tests Pose Threat, Las Vegas Review Journal/Sun, Sunday, June 16, 1991, Las Vegas, NV, pp. 1B.

Rojstaczer, S., 1991. Elastic Deformation as a Second Order Influence on Groundwater Flow in Areas of Crustal Unrest, AGU-MSA Spring Meeting 1991 Program and Abstracts, Supplement to EOS, April 23, 1991, American Geophysical Union, Vol. 72, No. 17, Washington, DC.

Rosenbaum, J. G., and M. R. Hudson, 1989. Paleomagnetic Investigation of Tertiary Structural Rotations at Yucca Mountain, Southern Nevada, in FOCUS '89, Proceedings of the Topical Meeting on Nuclear Waste Isolation in the Unsaturated Zone, September 17-21, 1989, Las Vegas, Nevada, American Nuclear Society, Inc., La Grange Park, IL, pp. 344-350.

Ross, B., S. Amter, and N. Lu, 1991. Numerical Studies of Rock-Gas Flow in Yucca Mountain, SAND91-7034, draft, Sandia National Laboratories, Albuquerque, NM.

Roy, D. M., and C. A. Langton, 1983. Characterization of Cement-Based Ancient Building Materials in Support of Repository Seal Materials Studies, BMI/ONWI-523, Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, OH.

Roy, D. M., and C. A. Langton, 1986. Ancient Concrete Studies as Analogs of Cementitious Sealing Materials for a Tuff Repository, unnumbered technical report, Materials Research Laboratory, Pennsylvania State University, University Park, PA.

Rudnicki, J. W., 1991. Pore Pressure Changes and Fluid Flow Induced by Opening Accompanying Normal Faulting Earthquakes, AGU-MSA Spring Meeting 1991 Program and Abstracts, Supplement to EOS, April 23, 1991, American Geophysical Union, Washington, DC, pp. 120-121.

Ruetz, J. W., 1987. The Geology of the Goldfield District, Bulk Mineable, J. L. Johnson (ed.), Geological Society of Nevada Guidebook for Field Trips, Reno, pp. 114-119.

Rulon, J., G. S. Bodvarsson, and P. Montazer, 1986. Preliminary Numerical Simulations of Groundwater Flow in the Unsaturated Zone, Yucca Mountain, Nevada, LBL-20553, Lawrence Berkeley Laboratory, Berkeley, CA.

Rundberg, R. S., J. L. Thompson, and S. Maestas, 1982. Radionuclide Migration: Laboratory Experiments with Isolated Fractures, in Scientific Basis for Nuclear Waste Management, Materials Research Society Symposium Proceedings, Vol. 6, Elsevier Science Publishing Co., Inc., NY, pp. 239-248.

Rundberg, R. S., A. J. Mitchell, M. A. Ott, J. L. Thompson, and I. R. Triay, 1989. Laboratory Studies of Radionuclide Migration in Tuff, in FOCUS '89, Proceedings of the Topical Meeting on Nuclear Waste Isolation in the Unsaturated Zone, September 17-21, 1989, Las Vegas Nevada, American Nuclear Society, Inc., La Grange Park, IL, pp. 248-255.

Rundberg, R. S., I. R. Triay, M. A. Ott, and A. J. Mitchell, 1991. Observation of Time Dependent Dispersion in Laboratory Scale Experiments with Intact Tuff, Radiochimica Acta, Vol. 52/53, pp. 219-228.

Rush, F. E., W. Thordarson, and D. G. Pyles, 1984. Geohydrology of Test Well USW H-1, Yucca Mountain, Nye County, Nevada, USGS-WRI-83-4032, Water-Resources Investigations Report, U.S. Geological Survey.

Russo, A. J., and D. C. Reda, 1988. Drying of an Initially Saturated Fractured Volcanic Tuff, SAND87-0293C, Sandia National Laboratories, Albuquerque, NM.

Ryall, A. S., and J. D. VanWormer, 1980. Estimation of Maximum Magnitude and Recommended Seismic Zone Changes in the Western Great Basin, Bulletin of the Seismological Society of America, Vol. 70, No. 5, pp. 1573-1582.

Ryder, E. E., 1991. Technical Considerations, Presentation to the Nuclear Waste Technical Review Board, October 8-10, 1991, Las Vegas, NV.

SAIC (Science Applications International Corporation), 1985. Tectonic Stability and Expected Ground Motion at Yucca Mountain, Report of a Workshop at SAIC-La Jolla, August 7-8, 1984 and January 25-26, 1985, DOE/NV/10270-2 (Rev. 1), SAIC 84/1847 (Rev. 1), Technical and Management Support Services, SAIC, Las Vegas, NV.

SAIC (Science Applications International Corporation), 1987. An Assessment of U.S. Air Force Aircraft Impact Frequency on the Yucca Mountain Waste Repository System, SAIC-87/8017, draft, Technical and Management Support Services, SAIC, Las Vegas, NV.

SAIC (Science Applications International Corporation), 1990. Yucca Mountain Project Meteorological Monitoring Program Thirteenth Quarterly Data Report, December 1988 through February 1989, Las Vegas, NV.

SAIC/DRI (Science Applications International Corporation/Desert Research Institute), 1991. Special Nevada Report, unnumbered report, Las Vegas, Nevada, available from National Technical and Information Services, Springfield, VA.

SNL (Sandia National Laboratories), 1987. Site Characterization Plan Conceptual Design Report, SAND84-2641, 6 Volumes, Sandia National Laboratories, Albuquerque, NM.

Saltus, R. W., 1988a. Gravity Data for the State of Nevada on Magnetic Tape, USGS-OFR-88-433, Open-File Report, U.S. Geological Survey.

Saltus, R. W., 1988b. Bouguer Gravity Anomaly and Topographic Maps and Isostatic Region and Residual Gravity Maps, Nevada Bureau of Mines and Geology Map 94B, Sheets 1 and 2, Scale 1:1,000,000, University of Nevada, Reno.

Saltus, R. W., 1988c. Regional, Residual, and Derivative Gravity Maps of Nevada, Nevada Bureau of Mines and Geology Map 94b, Sheets 3 and 4, Scale 1:1,000,000, University of Nevada, Reno.

Sass, J. H., A. H. Lachenbruch, R. J. Munroe, G. W. Greene, and T. H. Moses, Jr., 1971. Heat Flow in the Western United States, Journal of Geophysical Research, Vol. 76, No. 26, pp. 6376-6413.

Sass, J. H., A. H. Lachenbruch, W. W. Dudley, Jr., S. S. Priest, and R. J. Munroe, 1988. Temperature, Thermal Conductivity, and Heat Flow Near Yucca Mountain, Nevada: Some Tectonic and Hydrologic Implications, USGS-OFR-87-649, Open-File Report, U.S. Geological Survey, 118 pp.

Schafer, R. W., and P. G. Vikre, 1988. Introduction: Bulk Mineable Precious Metal Deposits: Nevada's Contribution to U.S. Gold Production, in Bulk Mineable Precious Metal Deposits of the Western United States, Symposium Proceedings, R. W. Schafer, J. J. Cooper, and P. G. Vikre (eds.), The Geological Society of Nevada, Reno, pp. 1-9.

Schumm, S. A., 1963. The Disparity Between Present Rates of Denudation and Orogeny, U.S. Geological Survey Professional Paper 454-H, U.S. Government Printing Office, Washington, DC, pp. H1-H13.

Schumm, S. A., and R. J. Chorley, 1983. Geomorphic Controls on the Management of Nuclear Waste, NUREG/CR-3276, U.S. Nuclear Regulatory Commission, Washington, DC.

Schwartz, B. M., 1990. SNL Yucca Mountain Project Data Report: Density and Porosity Data for Tuffs From the Unsaturated Zone at Yucca Mountain, Nevada, SAND88-0811, Sandia National Laboratories, Albuquerque, N. Mex.

Schweickert, R. A., 1989. Evidence for a Concealed Dextral Strike-Slip Fault Beneath Crater Flat, Nevada, Annual Meeting Geological Society of America, November 6-9, 1989, St. Louis, Missouri, Abstracts with Programs, p. A90.

Schweickert, R. A., and S. J. Caskey, 1990. Pre-Middle Miocene Extensional History of the Nevada Test Site (NTS) Region, Southern Nevada, Annual Meeting Geological Society of America, Cordilleran Section, March 14-16, 1990, Tuscon, Arizona, Abstracts with Programs, Vol. 22, No. 3.

Scott, C., and A. K. Chamberlain, 1987a. Blackburn Field, Nevada: A Case History, Oil and Gas Journal, August 17, 1987, 4 pp.

Scott, C., and A. K. Chamberlain, 1987b. Blackburn Field, Eureka County, Nevada: A Case History, AAPG Bulletin, Vol. 71, No. 8, p. 1014.

Scott, C., and A. K. Chamberlain, 1987c. Blackburn Field, Eureka County, Nevada: A Case History, AAPG Bulletin, Vol. 71, No. 5, p. 611.

Scott, R. B., 1988. Tectonic Setting of Yucca Mountain, Southwest Nevada, Annual Meeting Geological Society of America, Cordilleran Section, March 29-31, 1988, Las Vegas, Nevada, Abstracts with Programs, Vol. 20, p. 229.

Scott, R. B., 1989a. Isostatic Uplift, Crustal Attenuation, and the Evolution of an Extensional Detachment System in Southwestern Nevada, Selected papers from the Workshop, Late Cenozoic Evolution of the Southern Great Basin, November 10-13, 1987, University of Nevada, Reno, Nevada Bureau of Mines and Geology, Open File 89-1, pp. 19-26.

Scott, R. B., 1989b. Structural Geology of Yucca Mountain, in FOCUS '89, Proceedings of the Topical Meeting on Nuclear Waste Isolation in the Unsaturated Zone, September 17-21, 1989, Las Vegas, Nevada, American Nuclear Society, Inc., La Grange Park, IL, p. 325.

Scott, R. B., 1990. Tectonic Setting of Yucca Mountain, Southwest Nevada, Basin and Range Extensional Tectonic Near the Latitude of Las Vegas, Nevada, B. P. Wernicke (ed.), Geological Society of America Memoir 176, Boulder, CO, pp. 251-282.

Scott, R. B., and J. Bonk, 1984. Preliminary Geologic Map of Yucca Mountain, Nye County, Nevada, with Geologic Sections, Map USGS-OFR-84-494, Open-File Report, U.S. Geological Survey.

Scott, R. B., and J. G. Rosenbaum, 1986. Evidence of Rotation About a Vertical Axis during Extension at Yucca Mountain, Southern Nevada, EOS, Transactions, American Geophysical Union, Vol. 67, No. 16, p. 358.

Scott, R. B., and J. W. Whitney, 1987. The Upper Crustal Detachment System at Yucca Mountain, SW Nevada, Annual Meeting Geological Society of America, Rocky Mountain Section, May 2-4, 1987, Boulder, Colorado, Abstracts with Programs, pp. 332-333.

Scott, R. B., R. W. Spengler, S. Diehl, A. R. Lappin, and M. P. Chornak, 1983. Geologic Character of Tuffs in the Unsaturated Zone at Yucca Mountain, Southern Nevada, Role of the Unsaturated Zone in Radioactive and Hazardous Waste Disposal, J. W. Mercer, P. S. C. Rao, and I. W. Marine (eds.), Ann Arbor Science Publishers, Ann Arbor, MI, pp. 289-335.

Shaddrick, D. R., E. L. B. Hunsaker, and P. Hafen, 1988. Precious Metal Deposits of West-Central Nevada: An Overview, International Meeting on Gold Exploration: Techniques, Concepts, and Problems, October, 13-15, 1988, Society of Mining Engineers, Reno, NV.

Sheridan, M. F., 1990. Volcano Occurrences, Section 4, Demonstration of a Risk-Based Approach to High-Level Waste Repository Evaluation, EPRI NP-7057, Section 4, Electric Power Research Institute, Palo Alto, CA.

Shuman, R., J. G. Danna, and V. C. Rogers, 1991. Preliminary Sensitivity Studies for a HLW Repository Site Suitability Evaluation Methodology, RAE-9116/2-1, Rogers and Associates Engineering Corp., Salt Lake City, UT.

Sillitoe, R. H., 1988. Ores in Volcanoes, in Proceedings of the Seventh Quadrennial IAGOD Symposium, Schweizerbart'sche Verlagsbuchhandlung (Nagele u. Obermiller), Stuttgart.

Simonds, F. W., and R. B. Scott, 1987. Detachment Faulting and Hydrothermal Alteration in the Calico Hills, SW Nevada, EOS, Transactions, American Geophysical Union, Vol. 67, Washington, DC, p. 358.

Sinnock, S., 1989. Talk given to the Advisory Committee on Nuclear Waste, Bethesda, Maryland, March 1989.

Sinnock, S., and Y. T. Lin, 1989. Preliminary Estimates of Groundwater Travel Time at Yucca Mountain, Radioactive Waste Management and the Nuclear Fuel Cycle, Vol. 13(1-4), pp. 121-145.

Sinnock, S., Y. T. Lin, and J. P. Brannen, 1984. Preliminary Bounds on the Expected Postclosure Performance of the Yucca Mountain Repository Site, Southern Nevada, SAND84-1492, Sandia National Laboratories, Albuquerque, NM.

Sinnock, S., Y. T. Lin, and J. P. Brannen, 1987. Preliminary Bounds on the Expected Postclosure Performance of the Yucca Mountain Repository Site, Southern Nevada, Journal of Geophysical Research, Vol. 92, No. B8, pp. 7820-7842.

Sinnock, S. (ed.), Preliminary Estimates of Groundwater Travel Time and Radionuclide Transport at the Yucca Mountain Repository Site, SAND85-2701, Sandia National Laboratories, Albuquerque, NM.

Sinton, P. O., 1989. Characterization of the Large Hydraulic Gradient Beneath the North End of Yucca Mountain, Nevada, EOS, Transactions, American Geophysical Union, Vol. 70, No. 15, p. 321.

Smith, E. I., D. L. Feuerbach, T. R. Naumann, and J. E. Faulds, 1990. The Area of Most Recent Volcanism Near Yucca Mountain, Nevada: Implications for Volcanic Risk Assessment, in High Level Radioactive Waste Management, Proceedings of the International Topical Meeting, April 8-12, 1990, Las Vegas, Nevada, Vol. 1, American Nuclear Society, Inc., La Grange Park, IL, pp. 81-90.

Smith, P. L., and J. V. Tingley, 1983. Results of Geochemical Sampling within Esmeralda-Stateline Resource Area, Esmeralda, Clark, and Southern Nye Counties, Nevada, Nevada Bureau of Mines & Geology Open-File Report 83-12, draft, University of Nevada, Reno.

Smith, P., J. V. Tingley, J. L. Bentz, L. J. Garside, K. G. Papke, and J. Quade, 1983. A Mineral Inventory of the Esmeralda-Stateline Resource Area, Las Vegas District, Nevada, Nevada Bureau of Mines & Geology Open-File Report 83-11, draft, University of Nevada, Reno.

Spaulding, W. G., 1991. A Middle Holocene Vegetation Record from the Mojave Desert of North America and Its Paleoclimatic Significance, Quaternary Research, Vol. 35, pp. 427-437.

Spaulding, W. G., and L. J. Graumlich, 1986. The Last Pluvial Climatic Episodes in the Deserts of Southwestern North America, Nature, Vol. 320, pp. 441-444.

Spengler, R. W., and M. P. Chornack, 1984. Stratigraphic and Structural Characteristics of Volcanic Rocks in Core Hole USW G-4, Yucca Mountain, Nye County, Nevada, with a section on geophysical logs by D. C. Muller and J. E. Kibler, USGS-OFR-84-789, Open-File Report, U.S. Geological Survey.

Spengler, R. W., and K. F. Fox, Jr., 1989. Stratigraphic and Structural Framework of Yucca Mountain, Nevada, Radioactive Waste Management and the Nuclear Fuel Cycle, Vol. 13(1-4), pp. 21-36.

Squires, R. R., and R. L. Young, 1984. Flood Potential of Fortymile Wash and Its Principal Southwestern Tributaries, Nevada Test Site, Southern Nevada, USGS-WRI-83-4001, Water-Resources Investigations Report, U.S. Geological Survey.

Stager, H. K., and J. V. Tingley, 1988. Tungsten Deposits in Nevada, Nevada Bureau of Mines and Geology Bulletin 105, University of Nevada, Reno.

State of Nevada, 1984. Hazardous Materials, Memorandum of Understanding to implement Hazardous Materials Accident Assistance Plan, Nevada Division of Emergency Management.

Stevens, A. L., and L. S. Costin, 1991. Findings of the ESF Alternatives Study, SAND90-3232, Sandia National Laboratories, Albuquerque, NM.

Stevens, C. H., P. Stone, and P. Belasky, 1991. "Paleogeographic and Structural Significance of an Upper Mississippian Facies Boundary in Southern Nevada and East-Central California," Geological Society of America Bulletin, Vol. 103, No. 7, pp. 876-885.

Stewart, J. H., 1985. East-Trending Dextral Faults in the Western Great Basin: An Explanation for Anomalous Trends of Pre-Cenozoic Strata and Cenozoic Faults, Tectonics, Vol. 4, No. 6, pp. 547-564.

Stine, S., 1990. Late Holocene Fluctuations of Mono Lake, Eastern California, Palaeogeography, Palaeoclimatology, Palaeoecology, Vol. 78, pp. 333-381.

Stock, J. M., J. H. Healy, S. H. Hickman, and M. D. Zoback, 1985. Hydraulic Fracturing Stress Measurements at Yucca Mountain, Nevada, and Relationship to the Regional Stress Field, Journal of Geophysical Research, Vol. 90, No. B10, pp. 8691-8706.

Stoffle, R. W., J. E. Olmsted, and M. J. Evans, 1990a. Literature Review and Ethnohistory of Native American Occupancy and Use of the Yucca Mountain Area, DOE/NV-10576-21, Interim Report, Technical and Management Support Services, Science Applications International Corporation, Las Vegas, NV.

Stoffle, R. W., D. B. Halmo, J. E. Olmsted, and M. J. Evans, 1990b. Native American Cultural Resource Studies at Yucca Mountain, Nevada, Institute for Social Research, The University of Michigan, Ann Arbor.

Stuckless, J. S., 1991. An Evaluation of Evidence Pertaining to the Origin of Vein Deposits Exposed in Trench 14, Nevada Test Site, Nevada, in High Level Radioactive Waste Management, Proceedings of the Second Annual International Conference, April 28-May 3, 1991, Las Vegas, Nevada, Vol. 2, American Nuclear Society, La Grange Park, IL, pp. 1429-1438.

Subramanian, C. V., 1989. Cost-Benefit Assessment of the Seismic Design of the Tuff Repository Waste Handling Facilities, in Second DOE Natural Phenomena Hazards Mitigation Conference-1989, SAND89-0734C, Sandia National Laboratories, Albuquerque, NM.

Subramanian, C. V., N. Abrahamson, A. H. Hadjian, L. J. Jardine, J. B. Kemp, O. K. Kiciman, C. W. Ma, J. King, W. Andrews, and R. P. Kennedy, 1989. Preliminary Seismic Design Cost-Benefit Assessment of the Tuff Repository Waste-Handling Facilities, SAND88-1600, Sandia National Laboratories, Albuquerque, NM.

Subramanian, C. V., J. L. King, D. M. Perkins, R. W. Mudd, A. M. Richardson, J. C. Calovini, E. Van Eeckhout, and D. O. Emerson, 1990. Exploratory Shaft Seismic Design Basis Working Group Report, SAND88-1203, Sandia National Laboratories, Albuquerque, NM.

Swadley, W C, 1983. Map Showing Surficial Geology of the Lathrop Wells Quadrangle, Nye County, Nevada, U.S. Geological Survey Miscellaneous Investigations Series Map I-1361, Scale 1:48,000, U.S. Geological Survey.

Swadley, W C, and W. J. Carr, 1987. Geologic Map of the Quaternary and Tertiary Deposits of the Big Dune Quadrangle, Nye County, Nevada, and Inyo County, California, Miscellaneous Investigations Series Map I-1767, Scale 1:48,000, U.S. Geological Survey.

Swadley, W C, and D. L. Hoover, 1983. Geology of Faults Exposed in Trenches in Crater Flat, Nye County, Nevada, USGS-OFR-83-608, Open-File Report, U.S. Geological Survey.

Swadley W C, and H. E. Huckins, 1990. Geologic Map of the Surficial Deposits of the Skull Mountain Quadrangle, Nye County, Nevada, Miscellaneous Investigations Series, Map I-1972, Scale 1:24,000, U.S. Geological Survey.

Swadley, W C, and L. D. Parrish, 1988. Surficial Geologic Map of the Bare Mountain Quadrangle, Nye County, Nevada, Miscellaneous Investigations Series Map I-1826, Scale 1:62,500, U.S. Geological Survey.

Swadley, W C, D. L. Hoover, and J. N. Rosholt, 1984. Preliminary Report on Late Cenozoic Faulting and Stratigraphy in the Vicinity of Yucca Mountain, Nye County, Nevada, USGS-OFR-84-788, Open-File Report, U.S. Geological Survey.

Szabo, B. J. and T. K. Kyser, 1990. Ages and Stable-Isotope Compositions of Secondary Calcite and Opal in Drill Cores from Tertiary Volcanic Rocks of the Yucca Mountain Area, Nevada, Geological Society of America Bulletin, Vol. 102, pp. 1714-1719.

Szabo, B. J., W. J. Carr, and W. C. Gottschall, 1981. Uranium-Thorium Dating of Quaternary Carbonate Accumulations in the Nevada Test Site Region, Southern Nevada, USGS-OFR-81-119, Open-File Report, U.S. Geological Survey.

Szymanski, J. S., 1989. Conceptual Considerations of the Yucca Mountain Groundwater System with Special Emphasis on the Adequacy of This System to Accommodate a High-Level Nuclear Waste Repository, unnumbered report, 3 Volumes, U.S. Department of Energy, Nevada Operations Office, Las Vegas, NV.

Tarr A. C., and A. M. Rogers, 1986. Analysis of Earthquake Data Recorded by Digital Field Seismic Systems, Jackass Flats, Nevada, USGS-OFR-86-420, Open-File Report, U.S. Geological Survey, 67 pp.

Taylor, E. M., 1986. Impact of Time and Climate on Quaternary Soils in the Yucca Mountain Area of the Nevada Test Site, unpublished M.S. thesis, University of Colorado, Boulder.

Taylor, E. M., and H. E. Huckins, 1986. Carbonate and Opaline Silica Fault-Filling on the Bow Ridge Fault, Yucca Mountain, Nevada--Deposition from Pedogenic Processes or Upwelling Ground Water?, Annual Meeting Geological Society of America, Rocky Mountain Section, April 30-May 2, 1986, Flagstaff, Arizona, Abstracts with Programs, Vol. 18, No. 5, p. 418.

Thenhaus, P. C., and R. L. Wheeler, 1989. A New Generation of Probabilistic Ground-Motion Hazard Maps; Seismic Source Zones Revisited, in a workshop on USGS's New Generation of Probabilistic Ground Motion Mass and Their Application to Building Codes, Proceedings of Conference XLVII, OFR-89-0364, Open-File Report, U.S. Geological Survey, pp. 41-44.

Thomas, K. W., 1987. Summary of Sorption Measurements Performed with Yucca Mountain, Nevada, Tuff Samples and Water from Well J-13, LA-10960-MS, Los Alamos National Laboratory, Los Alamos, NM, 101 pp.

Thomas, K. W., (comp.) 1988. Research and Development Related to the Nevada Nuclear Waste Storage Investigations, October 1-December 31, 1984, LA-11443-PR, Los Alamos National Laboratory, Los Alamos, NM.

Thompson, J. L., 1989. Actinide Behavior on Crushed Rock Columns, Journal of Radioanalytical and Nuclear Chemistry, Vol. 130, No. 2, pp. 353-364.

Thompson, R. S., C. Whitlock, S. P. Harrison, W. G. Spaulding, and P. J. Bartlein, 1992. Late Quarternary History of Vegetation and Climate in the Western United States, in Global Climates Since the Last Glacial Maximum, H. E. Wright, Jr., J. E. Kutzbach, T. Webb III, W. F. Rudiman, F. A. Street-Perrot, and P. J. Bartlein, eds., University of Minnesota Press, Minnesota (in press).

Thompson, S. L., T. J. Crowley, G. J. Kukla, R. P. Sandoval, F. Gelbard, and Y. K. Behl, 1991. Study Plan for SCP Study 8.3.1.5.1.6: Characterization of the Future Regional Climate and Environments, YMP-SNL-SP 8.3.1.5.1.6, SAND91-0514, Rev. 0, Sandia National Laboratories, Albuquerque, NM.

Thordarson, W., 1983. Geohydrologic Data and Test Results from Well J-13, Nevada Test Site, Nye County, Nevada, USGS-WRI-83-4171, Water-Resources Investigations Report, U.S. Geological Survey.

Thorstenson, D. C., H. Haas, E. P. Weeks, and J. C. Woodward, 1989. Physical and Chemical Characteristics of Topographically Affected Airflow in an Open Borehole at Yucca Mountain, Nevada, in FOCUS '89, Proceedings of the Topical Meeting on Nuclear Waste Isolation in the Unsaturated Zone, American Nuclear Society, La Grange Park, IL, pp. 256-270.

Throckmorton, C. K., 1987. Photogeologic Study of Small-Scale Linear Features Near a Potential Nuclear-Waste Repository Site at Yucca Mountain, Southern Nye County, Nevada, USGS-OFR-87-409, Open-File Report, U.S. Geological Survey.

Tien, C., and A. C. Payatakes, 1979. Advances in Deep Bed Filtration, AICHE Journal Vol. 25, No. 5, pp. 737-759.

Tingley, J. V., 1984. Trace Element Associations in Mineral Deposits, Bare Mountain (Fluorine) Mining District, Southern Nye County, Nevada, Nevada Bureau of Mines and Geology Report 39, University of Nevada, Reno. 28 pp.

Tingley, S. L., and L. P. Newman, 1991. Nevada Bureau of Mines and Geology Publications Through 1989, An Annotated Bibliography with Index, Nevada Bureau of Mines and Geology Special Publication 12, Mackay School of Mines, University of Nevada, Reno.

Travis, B. J., 1984. TRACR3D: A Model of Flow and Transport in Porous/Fractured Media, LA-9667-MS, Los Alamos National Laboratory, Los Alamos, NM.

Treher, E. N., and N. A. Raybold, 1982. The Elution of Radionuclides Through Columns of Crushed Rock from the Nevada Test Site, LA-9329-MS, Los Alamos National Laboratory, Los Alamos, NM.

Trexler, D. T., T. Flynn, and B. A. Koenig, 1979. Assessment of Low-to-Moderate Temperature Geothermal Resources of Nevada, Final Report for the Period April 1978-June 1979, NVO/01556-1, Nevada Bureau of Mines & Geology, University of Nevada, Reno.

Triay, I. R., A. J. Mitchell, and M. A. Ott, 1991a. Radionuclide Migration as a Function of Mineralogy, in High Level Radioactive Waste Management, Proceedings of the Second International Conference, Las Vegas, Nevada, April 28-May 3, 1991, Vol. 1, American Nuclear Society, Inc., La Grange Park, IL, pp. 494-498.

Triay, I. R., D. E. Hobart, A. J. Mitchell, T. W. Newton, M. A. Ott, P. D. Palmer, R. S. Rundberg, and J. L. Thompson, 1991b. Size Determinations of Plutonium Colloids Using Autocorrelation Photon Spectroscopy, Radiochimica Acta, Vol. 52/53, p. 127.

Triay, I. R., A. Meijer, M. R. Cisneros, G. G. Miller, A. J. Mitchell, M. A. Ott, D. E. Hobart, P. D. Palmer, R. E. Perrin, and R. D. Aguilar, 1991c. Sorption of Americium in Tuff and Pure Minerals Using Synthetic and Natural Groundwaters, Radiochimica Acta, Vol. 52/53, pp. 141-145.

Turrin, B. D. and D. E. Champion, 1991. 40Ar/39Ar Laser Fusion and K-Ar Ages from Lathrop Wells, Nevada, and Cima, California: The Age of the Latest Volcanic Activity in the Yucca Mountain Area, in High Level Radioactive Waste Management, Proceedings of the Second Annual International Conference, April 28-May 3, 1991, Las Vegas, Nevada, Vol. 1, American Nuclear Society, Inc., La Grange Park, IL, pp. 68-75.

Tyler, S. W., and S. W. Wheatcraft, 1990. Fractal Processes in Soil Water Retention, Water Resources Research, Vol. 26, No. 5, pp. 1047-1054.

URS/John A. Blume & Associates, 1986. Ground Motion Evaluations at Yucca Mountain, Nevada with Applications to Repository Conceptual Design and Siting, SAND85-7104, Sandia National Laboratories, Albuquerque, NM.

URS/John A. Blume & Associates, 1987. Technical Basis and Parametric Study of Ground Motion and Surface Rupture Hazard Evaluations at Yucca Mountain, Nevada, SAND86-7013, Sandia National Laboratories, Albuquerque, NM.

USGS (U.S. Geological Survey) (comp.), 1984. A Summary of Geologic Studies through January 1, 1983, of a Potential High-Level Radioactive Waste Repository Site at Yucca Mountain, Southern Nye County, Nevada, USGS-OFR-84-792, Open-File Report, U.S. Geological Survey.

USGS Hydrologists and Hydrologic Technicians, 1988. Internal memorandum from USGS Hydrologists and Hydrologic Technicians to V. Schneider, August 17, 1988; regarding USGS Role in Yucca Mountain Site Characterization Effort.

Updegraff, C. D., C. E. Lee, and D. P. Gallegos, 1991. DCM3D: A Dual-Continuum, Three-Dimensional, Ground-Water Flow Code for Unsaturated, Fractured, Porous Media, NUREG/CR-5536, SAND90-7015, U.S. Nuclear Regulatory Commission, Washington, DC.

Vaniman, D., and B. Crowe, 1981. Geology and Petrology of the Basalts of Crater Flat: Applications to Volcanic Risk Assessment for the Nevada Nuclear Waste Storage Investigations, LA-8845-MS, Los Alamos National Laboratory, Los Alamos, NM, 67 pp.

Vaniman, D. T., B. M. Crowe, and E. S. Gladney, 1982. Petrology and Geochemistry of Hawaiite Lavas from Crater Flat, Nevada, Contributions to Mineralogy and Petrology, Vol. 80, pp. 341-357.

Vaniman, D. T., D. L. Bish, and S. Chipera, 1988. A Preliminary Comparison of Mineral Deposits in Faults near Yucca Mountain, Nevada, with Possible Analogs, LA-11289-MS, Los Alamos National Laboratory, Los Alamos, NM, 59 pp.

Van Konynenburg, R. A., 1991. Gaseous Release of Carbon-14: Why the High Level Waste Regulations Should be Changed, in High Level Radioactive Waste Management, Proceedings of the Second International Conference, April 28-May 3, 1991, Las Vegas, Nevada, Vol. 1, American Nuclear Society, Inc., La Grange Park, IL, pp. 313-319.

Veal, H. K., H. D. Duey, L. C. Bortz, and N. H. Foster, 1988. Basin and Range May Hold More Big Fields, Oil and Gas Journal, Vol. 86, No. 13, pp. 56-59.

Vogel, T. A., and F. M. Byers, Jr., 1989. Introduction to the Special Section on the Southwestern Nevada Volcanic Field, Journal of Geophysical Research, Vol. 94, No. B5, p. 5907.

Voss, C. I., 1984. A Finite Element Simulation Model for Saturated-Unsaturated, Fluid-Density-Dependent Ground-Water Flow with Energy Transport or Chemically-Reactive Single-Species Solute Transport, USGS-WRO-84-436, Water-Resources Investigations Report U.S. Geological Survey.

Waag, C. J., 1991. Groundwater Eruptions and Sediment Boil Formation Attendant to the Borah Peak, Idaho, Earthquake, AGU-MSA Spring Meeting 1991 Program and Abstracts, Supplement to EOS, April 23, 1991, American Geophysical Union, Washington, DC, p. 115.

Waddell, R. K., 1982. Two-Dimensional, Steady-State Model of Ground-Water Flow, Nevada Test Site and Vicinity, Nevada-California, USGS-WRI-82-4085, Water-Resources Investigations Report, U.S. Geological Survey.

Wagner, J. C., J. W. Skidmore, R. J. Hill, and D. M. Griffiths, 1985. Erionite Exposure and Mesotheliomas in Rats, Journal of Cancer, Vol. 28, pp.727-730.

Walck, M. C., and J. S. Phillips, 1990. Two-dimensional Velocity Models for Paths from Pahute Mesa and Yucca Flat to Yucca Mountain, SAND88-3033, Sandia National Laboratories, Albuquerque, NM.

Wang, J. S. Y., 1991. Flow and Transport in Fractured Rocks, Reviews of Geophysics, Supplement, U.S. National Report to International Union of Geodesy and Geophysics 1987-1990, pp. 254-262.

Wang, J. S. Y., and T. N. Narasimhan, 1985. Hydrologic Mechanisms Governing Fluid Flow in Partially Saturated, Fractured Porous Tuff at Yucca Mountain, SAND84-7202, Sandia National Laboratories, Albuquerque, NM.

Wang, J. S. Y., and T. N. Narasimhan, 1987. Hydrologic Modeling of Vertical and Lateral Movement of Partially Saturated Fluid Flow Near a Fault Zone at Yucca Mountain, SAND87-7070, Sandia National Laboratories, Albuquerque, NM.

Wang, J. S. Y., and T. N. Narasimhan, 1990. Fluid Flow in Partially Saturated, Welded-Nonwelded Tuff Units, Geoderma, Vol. 46, Nos. 1-3, pp. 155-168.

Weeks, E. P., 1987. Effect of Topography on Gas Flow in Unsaturated Fractured Rock: Concepts and Observations, Flow and Transport Through Unsaturated Fractured Rock, D. D. Evans and T. J. Nicholson (eds.), Geophysics Monograph 42, American Geophysical Union, pp. 165-170.

Weiss, S. I., K. A. Connors, D. C. Noble, and E.H. McKee 1990. Coeval Crustal Extension and Magmatic Activity in the Bullfrog Hills during the Latter Phases of Timber Mountain Volcanism, Annual Meeting Geological Society of America, Cordilleran Section, March 14-16, 1990, Tucson, Arizona, Abstracts with Programs, Vol. 22, No. 3.

Wells, S. G., L. D. McFadden, C. Renault, and B. M. Crowe, 1988. A Geomorphic Assessment of Quaternary Volcanism in the Yucca Mountain Area, Nevada Test Site, Southern Nevada, Annual Meeting Geological Society of America, Cordilleran Section, March 29-31, 1988, Las Vegas, Nevada, Vol. 20, No. 3, p. 242.

Wells, S. G., L. D. McFadden, C. E. Renault, and B. M. Crowe, 1990. Geomorphic Assessment of Late Quaternary Volcanism in the Yucca Mountain Area, Southern Nevada: Implications for the Proposed High-Level Radioactive Waste Repository, Geology, Vol. 18, pp. 549-553.

Wendland, W. M., 1991. General Circulation Models: Applications for Nuclear Waste Repositories, in High Level Radioactive Waste Management, Proceedings of the Second Annual International Conference, Las Vegas, Nevada, April 28-May 3, 1991, Vol. 2, American Nuclear Society, Inc., La Grange Park, IL, pp. 1439-1443.

Wesling, J. R., T. F. Bullard, F. H. Swan, R. C. Perman, M. M. Angell, and J. D. Gibson, 1991. Preliminary Mapping of Surficial Geology of Midway Valley, Yucca Mountain Project, Nye County, Nevada, SAND91-0607, Sandia National Laboratories, Albuquerque, NM.

West, K. A. 1988. Nevada Nuclear Waste Storage Investigations Exploratory Shaft Facility Fluids and Materials Evaluation, LA-11398-MS, Los Alamos National Laboratory, Los Alamos, NM.

Wetzel, N., and R. G. Raney, 1987. Oil and Gas Drilling in Clark, Esmeralda, Lincoln, and Nye Counties, Nevada 1920 through 1986, NRC FIN D1018, U.S. Nuclear Regulatory Commission, Washington, DC.

Whelan, J. F. and J. S. Stuckless, 1990. Reconnaissance $\delta^{13}C$ and $\delta^{18}O$ Data from Trench 14, Busted Butte, and Drill Hole G-4, Yucca Mountain, Nevada Test Site, in High level Radioactive Waste Management, Proceedings of the International Topical Meeting, April 8-12, 1990, Las Vegas, Nevada, Vol. 2, American Nuclear Society, Inc., La Grange Park, IL, pp. 930-933.

Whelan, J. F., and J. S. Stuckless, 1991. The $\delta^{13}C$ and $\delta^{18}O$ Values of Epigenetic Calcite within Yucca Mountain, Nevada: Paleohydrologic Implications, Annual Meeting Geological Society of America, October 21-24, 1991, San Diego, California, Abstracts with Programs, Vol. 23, No. 5, p. A117.

Whitfield, M. S., 1985. Vacuum Drilling of Unsaturated Tuffs at a Potential Radioactive-Waste Repository, Yucca Mountain, Nevada, preprint, in Proceedings of the NWWA Conference on Characterization and Monitoring of the Vadose (Unsaturated) Zone, November 19-21, 1985, Denver, Colo., CONF-8511172-4, National Water Well Association, Worthington, Ohio, pp. 413-423.

Whitfield, M. S., W. Thordarson, and D. P. Hammermeister, 1990. Drilling and Geohydrologic Data for Test Hole USW UZ-1, Yucca Mountain, Nye County, Nevada, USGS-OFR-90-354, Open-File Report, U.S. Geological Survey.

Whitney, J. W., and C. D. Harrington, 1988. Middle Pleistocene Colluvial Boulder Flows on Yucca Mountain in Southern Nevada, Annual Meeting Geological Society of America and associated societies, October 31-November 3, 1988, Denver, Colorado, Abstracts with Program, Vol. 20, No. 7, p. A348.

Whitney, J. W., and C. D. Harrington, in preparation. Relict Colluvial Boulder Deposits: Indicators of Climatic Change and Long-Term Slope Stability in the Yucca Mountain Region, Southern Nevada, preliminary draft, submitted to Geological Society of America Bulletin.

Whitney, J. W., and D. R. Muhs, 1991. Quaternary Movement on the Paintbrush Canyon-Stagecoach Road Fault System, Yucca Mountain, Nevada, Annual Meeting Geological Society of America, October 21-24, 1991, San Diego, California, Abstracts with Programs, Vol. 23, No. 5.

Whitney, J. W., R. R. Shroba, F. W. Simonds, and S. T. Harding, 1986. Recurrent Quaternary Movement on the Windy Wash Fault, Nye County, Nevada, Annual Meeting Geological Society of America, November 10-13, 1986, San Antonio, Texas, Abstracts with Programs, Vol. 18, No. 6, p. 787.

Winograd, I. J., and G. C. Doty, 1980. Paleohydrology of the Southern Great Basin, with Special Reference to Water Table Fluctuations Beneath the Nevada Test Site during the Late(?) Pleistocene, USGS-OFR-80-569, Open-File Report, U.S. Geological Survey.

Winograd, I. J., and B. J. Szabo, 1986. Water-Table Decline in the South-Central Great Basin during the Quaternary Period: Implications for Toxic-Waste Disposal, USGS-OFR-85-697, Open-File Report, U.S. Geological Survey.

Winograd, I. J., and B. J. Szabo, 1988. Water-Table Decline in the South-Central Great Basin During the Quaternary: Implications for Toxic Waste Disposal, Geologic and Hydrologic Investigations of a Potential Nuclear Waste Disposal Site at Yucca Mountain, Southern Nevada, M. D. Carr and J. C. Yount (eds.), U.S. Geological Survey Bulletin 1790, U.S. Geological Survey, pp. 147-152.

Winograd, I. J., and W. Thordarson, 1975. Hydrogeologic and Hydrochemical Framework, South-Central Great Basin, Nevada-California, with Special Reference to the Nevada Test Site, U.S. Geological Survey Professional Paper 712-C, U.S. Government Printing Office, Washington, DC, pp. C1-C126.

Winograd, I. J., B. J. Szabo, T. B. Coplen, and A. C. Riggs, 1988. A 250,000-Year Climatic Record from Great Basin Vein Calcite: Implications for Milankovitch Theory, Science, Vol. 242, pp. 1275-1280.

Wolfsberg, K., W. R. Daniels, D. T. Vaniman, and B. R. Erdal (compilers), 1982. Research and Development Related to the Nevada Nuclear Waste Storage Investigations, October 1-December 31, 1981, LA-9225-PR, Los Alamos National Laboratory, Los Alamos, NM.

Wood, S. H., 1991. Observations and Subsequent History of Spectacular Groundwater Flows and Aquifer Pressure Increases: 1983 Borah Peak and 1957 Hebgen Lake Earthquakes, AGU-MSA Spring Meeting 1991 Program and Abstracts, Supplement to EOS, April 23, 1991, American Geophysical Union, Washington, DC, p. 115.

Worman, F. C. V., 1969. Archeological Investigations at the U.S. Atomic Energy Commission's Nevada Test Site and Nuclear Rocket Development Station, LA-4125, Los Alamos National Laboratory, Los Alamos, NM.

Wright, L., 1989. Overview of the Role of Strike-Slip and Normal Faulting in the Neogene History of the Region Northeast of Death Valley, California-Nevada, Selected papers from the workshop, Late Cenozoic Evolution of the Southern Great Basin, November 10-13, 1987 Reno, Nevada, Nevada Bureau of Mines and Geology Open File 89-1, Reno, pp. 1-11.

Wu, S. S. C., 1985. Topographic Maps of Yucca Mountain Area, Nye County, Nevada, Map USGS-OFR-85-620, Open-File Report, Scale 1:5,000, U.S. Geological Survey.

Wycoff, R., 1988. Letter from R. Wycoff (Bureau of Land Management) to B. Kaiser (Yucca Mountain Project), October 17, 1988; regarding summary of a mineral reconnaissance conducted on the Yucca mining claims.

Yang, I. C., 1989. Climatic Changes Inferred from Analyses of Lake-Sediment Cores, Walker Lake, USGS-WRI-84-4006, Nevada, Water-Resources Investigations Report, U.S. Geological Survey.

Yang, I. C., A. K. Turner, T. M. Sayre, and P. Montazer, 1988. Triaxial-Compression Extraction of Pore Water from Unsaturated Tuff, Yucca Mountain, Nevada, USGS-WRI-88-4189, Water-Resources Investigations Report, U.S. Geological Survey.

Yeh, T. C., and D. B. Stephens, 1988. A Review of the Scale Problem and Applications of Stochastic Methods to Determine Groundwater Travel Time and Path, Daniel B. Stephens & Associates, Inc., Socorro, NM.

Young, A., 1972. Slopes, 2nd impression, Longman Inc., New York.

Young, S. R., G. L. Stirewalt, and R. A. Ratliff, 1991. Computer-Assisted Geometric and Kinematic Analysis of Subsurface Faulting in the Vicinity of Yucca Mountain, Nevada, Using Balanced Geologic Cross Sections, in High Level Radioactive Waste Management, Proceedings of the Second Annual International Conference, April 28 - May 3, 1991, Las Vegas, Nevada, Vol. 1, American Nuclear Society, Inc., La Grange Park, IL, pp. 248-259.

Youngs, R. R., F. H. Swan, and M. S. Power, 1988. Use of Detailed Geologic Data in Regional Probabilistic Seismic Hazard Analyses: An Example from the Wasatch Front Utah, in Proceedings of the American Society of Civil Engineers Conference on Earthquake Engineering and Soil Dynamics, II Recent Advances in Ground-Motion Evaluation, Geotechnical Special Publication No. 20, pp. 156-172.

Younker, J. L., W. B. Andrews, G. A. Fasano, C. C. Herrington, S. R. Mattson, R. C. Murray, L. B. Ballou, M. A. Revelli, A. R. Ducharme, L. E. Shepard, W. W. Dudley, D. T. Hoxie, R. J. Herbst, E. A. Patera, B. R. Judd, J. A. Docka, and L. D. Rickertsen, 1992. Report of the Peer Review Panel on the Early Site Suitability Evaluation of the Potential Repository Site at Yucca Mountain, Nevada, SAIC-91/8001, Technical and Management Support Services, Science Applications International Corporation, Las Vegas, NV

Yount, J. C., R. R. Shroba, C. R. McMasters, H. E. Huckins, and E. A. Rodriguez, 1987. Trench Logs from a Strand of the Rock Valley Fault System, Nevada Test Site, Nye County, Nevada, U.S. Geological Survey Miscellaneous Field Studies Map MF-1824, U.S. Geological Survey.

Zhang, P., 1989. Evaluation of the Geologic Relations and Seismotectonic Stability of the Yucca Mountain Area, Nevada Nuclear Waste Site Investigation (NNWSI), Draft, 2 volumes, Center for Neotectonic Studies, Mackay School of Mines, University of Nevada, Reno.

Zimmerman, R. M., M. L. Blanford, J. F. Holland, R. L. Schuch, and W. H. Barrett, 1986a. Final Report, G-Tunnel Small-Diameter Heater Experiments, SAND84-2621, Sandia National Laboratories, Albuquerque, NM.

Zimmerman, R. M., R. L. Schuch, D. S. Mason, M. L. Wilson, M. E. Hall, M. P. Board, R. P. Bellman, and M. L. Blanford, 1986b. Final Report: G-Tunnel Heated Block Experiment, SAND84-2620, Sandia National Laboratories, Albuquerque, NM.

Zimmerman, R. W., and G. S. Bodvarsson, 1989. An Approximate Solution for One-Dimensional Absorption in Unsaturated Porous Media, Water Resources Research Vol. 25, No. 6, pp. 1422-1428.

Zimmerman, R. W., G. S. Bodvarsson, and E. M. Kwicklis, 1990. Absorption of Water into Porous Blocks of Various Shapes and Sizes, Water Resources Research, Vol. 26, No. 11, pp. 2797-2806.

Zyvoloski, G., 1990. Simulation of Heat Transfer in the Unsaturated Zone, in High Level Radioactive Waste Management, Proceedings of the International Topical Meeting, Las Vegas, Nev., April 8-12, 1990, Vol. 1, American Nuclear Society, Inc., La Grange Park, IL, pp. 611-617.

CODES AND REGULATIONS

10 CFR Part 20, (Code of Federal Regulation), 1990. Title 10, Energy, Part 20, Standards for Protection Against Radiation, U.S. Government Printing Office, Washington, DC.

10 CFR Part 60 (Code of Federal Regulation), 1990. Title 10, Energy, Part 60, Disposal of High-Level Radioactive Wastes in Geologic Repositories, U.S. Government Printing Office, Washington, DC.

10 CFR Part 71 (Code of Federal Regulations), 1988. Title 10, Energy, Part 71, Packaging and Transportation of Radioactive Material, U.S. Government Printing Office, Washington, DC.

10 CFR Part 73 (Code of Federal Regulations), 1988. Title 10, Energy, Part 73, Physical Protection of Plants and Materials, U.S. Government Printing Office, Washington, DC.

10 CFR Part 960 (Code of Federal Regulation), 1984. Title 10, Energy, Part 960, General Guidelines for the Recommendation of Sites for the Nuclear Waste Repositories, U.S. Government Printing Office, Washington, DC.

40 CFR Part 191, (Code of Federal Regulation), 1990. Title 40, Protection of Environment, Part 191, Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, U.S. Government Printing Office, Washington, DC.

43 CFR Public Land Order 6802, 1990. Withdrawal of Public Land to Maintain the Physical Integrity of the Subsurface Environment, Yucca Mountain Project; Nevada, Federal Register, Vol. 55, No. 186, p. 39152.

49 CFR Part 173 (Code of Federal Regulations), 1990. Title 49, Transportation, Part 173, Shippers-General Requirements for Shipments and Packagings, U.S. Government Printing Office, Washington, DC.

49 CFR Part 174 (Code of Federal Regulations), 1990. Title 49, Transporation, Part 174, Carriage by Rail, U.S. Government Printing Office, Washington, DC.

49 CFR Part 177 (Code of Federal Regulations), 1990. Title 49, Transportation, Part 177, Carriage by Public Highway, U.S. Government Printing Office, Washington, DC.

★U.S. GOVERNMENT PRINTING OFFICE: 1992-686-180/79058